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Ecological effects of rainshowers on eastern Montana rangeland

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Ecological Effects of Rainshowers on Eastern Montana Rangeland

Progress Report 1977

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MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION
WATER RESOURCES DIVISION — MARCH 1978

NRIS 11694

Progress Report

Ecological Effects of Rainshowers on Eastern Montana Rangeland

1977

Prepared for the
Division of Atmospheric Water Resources Management
Bureau of Reclamation
U.S. Department of the Interior
Denver, Colorado 80225
Under Contract 14-06-D-7577

A Technical Report
by the
HIPLEX Research Project
Water Resources Division
Department of Natural Resources and Conservation
State of Montana

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ACKNOWLEDGEMENTS

We are very grateful to the personnel of the U.S. Livestock and Range Research Station at Miles City for granting us access to their land and for their valuable assistance. The cooperation and efforts of Waine Milmine are especially appreciated.

Our thanks go to Tom Zuelke for his untiring efforts in irrigating the plots and to Linda Gruenfelder for drafting the figures.

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SUMMARY

An experiment, designed to determine the short- and mid-term (six year) effects of an operational weather modification program on the native range ecosystem, was installed and initiated at two native rangeland sites near Miles City, Montana, in the spring of 1977. The two experimental sites, one dominated by *Agropyron smithii*, a cool season grass commonly known as western wheatgrass, and the other dominated by *Bouteloua gracilis*, a warm season grass commonly known as blue grama, were irrigated using six different irrigation treatments. This methodology was used to study the probable effects that supplemental rain from a cloud seeding program might have on the two grasses and the native rangeland ecosystems in which they are found.

The six irrigation treatments, each replicated once at each site included:

1. A control treatment in which no additional water was applied.
2. A spring wet treatment in which water was applied until late June to maintain soil water stresses at less than 2 bars and was designed to mimic the rainfall regime of Dickinson, North Dakota.
3. A 6 mm summer shower treatment in which 6 mm of water were guaranteed each week by supplementing natural rainfall with irrigation and was meant to simulate an increased frequency of small showers.
4. A 12 mm summer shower treatment in which 12 mm of water were guaranteed every two weeks by supplementing natural rainfall with irrigation and was meant to simulate less frequent but heavier showers than in the 6 mm summer shower treatment.
5. A fall wet treatment in which about 177 mm of water were guaranteed in four irrigations in mid-September and was meant to simulate heavy fall rains.

6. A constantly wet treatment in which soil water stresses were maintained by irrigation at less than two bars throughout the growing season to determine the response of vegetation when water is not a limiting factor.

Agropyron smithii and *Bouteloua gracilis* were chosen for study because, along with *Stipa comata* commonly known as needleandthread, they are the dominant native range grasses of the region.

A variety of growth and associated ecological responses were measured and some very early findings are summarized below.

1) Soil moisture, the control-independent variable, was measured weekly at three soil depths (10, 25, and 75 cm) with psychrometers and plaster 'Bouyoucos' blocks. Soils in the control and 6 and 12 mm summer shower plots dried to a depth of 75 cm by 15 June at the *Agropyron smithii* site and 1 July at the *Bouteloua gracilis* site. Soil moistures at the 10 cm depth in the summer shower plots were similar to those in the control plots suggesting that showers under 6 mm is a surface phenomenon with little effect on soil water. Soils of the spring wet plots dried about fifty days after watering had ceased in late June. Soils in the wet plots never dried. The *Agropyron smithii* treatment plots dried quicker than the *Bouteloua gracilis* plots probably because of the greater leaf area for transpiration at the *Agropyron smithii* site.

2) Plant water potentials followed soil water potentials at the 10 cm depth closely. Plant water stresses were relieved for short periods throughout the summer in the control and 6 and 12 mm summer shower plots whenever these plots received natural and irrigated showers providing more than 6 mm.

3) Plants stayed green longer on wet plots than on control plots. Flowering may have started earlier on the wet plots than on the control plots.

but maturity (or abortion) was reached slightly earlier on the control plots than on the wet plots.

4) Leaf growth was reduced greatly in mid-June when soil water stresses rose to significant levels of more than 15 bars. Growth responses to 12 mm natural and irrigated showers were seen, but is not clear whether *Agropyron smithii* plants are capable of responding to 6 mm showers. Data on *Bouteloua gracilis* are lacking, due to grasshopper infestation. Leaf growth in the wet plots was markedly higher than that observed in the control plots. When water was not limiting as in the wet plots, leaf growth began to decrease markedly after mid-June for *Agropyron smithii* and after late July for *Bouteloua gracilis*. These plants appear incapable of responding to more water after these times.

5) Despite the small leaf growth responses, the 6 and 12 mm summer shower plots yielded no economically significant increase in quantities of harvestable forage over the control plots.

6) Seed production of *Bouteloua gracilis*, but not of *Agropyron smithii*, increased in the wet and spring wet plots. The 6 and 12 mm summer showers appear to have little effect on seed production of either grass.

7) Root biomass increased markedly with season, but not with additional water. The addition of water resulted in a decrease in the root-shoot ratio because less water is needed to support vegetative growth.

8) Seven mesic native grasses were planted in all plots at both sites. Four of the moisture loving species of the central and eastern plains became established in the wet and spring wet plots, but none became established in the control and 6 and 12 mm summer shower plots. The more drought resistant grasses failed to establish in any plots. Several weedy species invaded each site.

9) No discernible increase in leaf spot fungi with additional water was observed in either rangeland site. Ergot, a fungus of seedheads which causes abortion in cattle, was present only in the *Agropyron smithii* site in the wet plots, but not in the control plots.

10) The rate of decomposition was enhanced slightly by watering at both sites.

11) Grasshopper damage was apparently greater on the control than on the wet plots. Since these insects are mobile, this may indicate a greater palatability for dry grasses.

12) Nitrogen and other chemical analyses of soils and vegetation are still under way. They will tell us whether grasses grown with additional water are protein poor, as the grasshopper data suggests, and whether nitrogen is being redistributed in the ecosystem.

13) In the single shower experiment, small plots were saturated with water in either July, August, or September. Forage production was measured in November. The result suggests that the capacity of plants to increase forage production declines with season and markedly after 1 August. This decline is associated with an increase in new culms.

In summary, these preliminary findings suggest that the timing and amount of additional rainfall is important. With unlimited water, *Agropyron smithii* grows more efficiently before mid-June and *Bouteloua gracilis* before August. Additions of water less than 6 mm appear to have little economic benefits after June, presumably, because the soil is drying and most of the water is lost by evaporation and little absorbed by the roots even though much of roots are in the upper 10 cm of the soil. Moreover, as the season progresses, growth of both grasses appears to be limited more by day length than by water. Additional water in late summer and early fall, however, did increase culm initiation and numbers which is important for forage production the following year. Also, since the additional water is not used in the fall, it could be stored in the soil and used by plants the following spring.

INTRODUCTION

To develop the technology of a precipitation enhancement program, HIPLEX non-meteorologists should first determine what storm characteristics such as seasonal distribution, frequency, intensities and quantities of rainfall, are most beneficial for society, agriculture, the environment, etc. Second, the research meteorologists of HIPLEX must determine how these storm characteristics can be modified for the benefit of society, agriculture, the environment, etc. Third, HIPLEX researches must then determine what practical ways are available for combining this information to carry out a successful weather modification program. This study is concerned with determining the best storm characteristics needed to increase native range production, and the effects these storm characteristics will have on the native range ecosystem of the northern High Plains.

Growth and ecological responses are being compared between a natural rangeland and a rangeland giving different patterns of watering simulating different storm patterns. Local native range vegetation was selected for this study because it is the dominant vegetation in eastern Montana, eastern Wyoming, eastern Colorado, the western Dakotas and western Nebraska. Six different storm patterns were simulated by irrigating constantly through June to simulate heavy spring rains, irrigating in amounts sufficient to guarantee 6 mm of water weekly to simulate frequent light showers, irrigating in amounts sufficient to guarantee 12 mm of water fortnightly to simulate less frequent but heavier showers, irrigating heavily in fall to simulate heavy fall rains, irrigating constantly, and not irrigating at all. A parallel experiment was also conducted to determine the effects of a single heavy shower occurring in July, August or September. These irrigation treatments will be discussed in more detail under "The Treatments."

To examine the responses of native range ecosystems to increased water, the following objectives are being pursued:

1) measuring the effects of additional rainfall on phenology, forage production, and seed production,

2) determining the relationship between plant growth and soil and plant water potential,

3) determining the effects of additional water on certain aspects of ecosystem structure and function such as root-shoot ratios, nitrogen distribution, and decomposition rates, and

4) determining the stability of grasslands under increased rainfall.

This report was written to provide the Bureau of Reclamation with the preliminary findings from the first year of this study and to assist us in defining our research needs for the 1978 field season.

THE STUDY AREAS

Two grassland sites, one dominated by *Agropyron smithii* (western wheatgrass) and the other by *Bouteloua gracilis* (blue grama), were selected because they are the principle range grasses (along with *Stipa comata*) of the northern Great Plains. Both study sites lie on the U.S. Livestock and Range Research Station near Miles City, Montana.

The soils of both sites were classified by the U.S. Soil Conservation Service. At the *Agropyron smithii* site, the soil is a Borollic Camborthid with a silty-clay-loam texture and a calcareous layer at 20 cm (Kobar Series). At the *Bouteloua gracilis* site, the soil is a Ustic Torri-fluvent with a fine-loamy texture and a calcareous layer at 8 cm (Havre Series). Both sites have slopes of less than 2% and ground water levels below 2 meters.

Weather records are being kept during the growing season at each site and include: solar radiation (recording solarimeter), air temperature (Hygrothermograph and max-min thermometers), soil temperature at 10, 25, and 75 cm (distance thermographs), precipitation (Belfort weighing raingages and wedge gages), humidity (hygrothermographs and psychrometers), and wind speed (totalizing anemometers). Long term weather records representative of the region are available at Miles City Airport and within Miles City, and will be analyzed for comparison.

THE TREATMENTS

To accommodate the six different irrigation treatments each site was divided into twelve 21.3 x 21.3 m plots and the treatments were randomly assigned to the twelve plots. The actual experimental plots measured 14 x 14 m and were centered inside the larger plots. Each experimental plot was subdivided into nine 1.2 x 14 m strips to allow separate measurement of a variety of responses described under "The Responses."

The six treatments that were applied were named "spring wet," "6 mm summer shower," or "6 mm treatment," "12 mm summer shower" or "12 mm treatment," "fall wet," "constantly wet," and "control."

The spring wet treatment maintained soil water stresses at a level below two bars through July by heavy irrigation until late June. It was meant to simulate a very successful spring cloud seeding program in which the shortgrass climate is transformed into a mixed grass climate like that under the rainfall regime of Dickinson, North Dakota. Under this treatment the soils remained wet until late July of 1977.

The 6 mm summer shower or 6 mm treatment involved slight additions of water to supplement the water provided by natural summer showers and resulted in an increased frequency of wetting the surface soils. At least 6 mm of water was guaranteed each week to plots under this treatment by supplementing rainfall with irrigation. The treatment was meant to simulate a cloud seeding program that provided frequent light showers. Plots under this treatment received approximately 25 mm of additional water in several small sprinklings in 1977.

The 12 mm summer shower or 12 mm treatment also involved slight additions of water supplemental to natural rainfall but was meant to simulate heavier but less frequent summer showers. This treatment guaranteed 12 mm of water every two weeks to experimental plots by supplementing rainfall with irrigation. Although plots under this treatment received an additional 15 mm of water, the soil moisture readings in these plots were similar to that in the control plots.

The fall wet treatment was designed to simulate the results of a very successful fall cloud seeding program and was identical to the control until mid-September when about 177-178 mm of water were applied to plots under this treatment in four irrigations. During these irrigations, the upper 75 cm of soil was saturated.

The constantly wet treatment was designed to determine how native vegetation would respond when water is not a limiting factor. Soil water stresses were maintained less than two bars.

Although four treatments were meant to simulate possible weather modifications through irrigation, the control involved no supplemental irrigation and was intended to be used to determine the response to natural conditions.

A parallel experiment was conducted to determine the effects of a single heavy shower during the summer. Plots under this experiment received irrigation once in July, August or September saturating the soil to a depth of 25 cm.

Monthly amounts of precipitation and irrigation water falling on the plots are summarized in Tables 1 and 2. Please note that large amounts of water were added to the spring wet and constantly wet plots. All additional irrigations should not be considered equivalent to rainfall due to the "oasi effect." Irrigation water is lost from the soil and from the surface of pla through evaporation to a greater degree than water received from a rain shower. A quantitative study of this oasis effect on the two study sites is planned to begin in 1978.

The water supplements were added to each plot with four "Rainjet" sprinklers set 45 cm above ground level and positioned to provide uniform coverage. Water was pumped from the Yellowstone River at the *Agropyron smithii* site and Tongue River at the *Boutelous gracilis* site. Large particulate matter was removed with filters and centrifugal separators. The salt content of the river water was measured periodically. To prevent lateral movement of water between plots, a 7.4 m wide buffer strip separated each plot and water was not applied when the wind speed exceeded three miles per hour. Figure 1 shows the design of the irrigation system at the *Agropyron smithii* site and figure 2 shows Tom Zuelke irrigating the wet plot at the *Bouteloua gracilis* site.

For a further description of the objectives and methodology, refer to the proposal entitled, "Ecological Effects of Precipitation Enhancement on Eastern Montana Rangeland." (Appendix I)

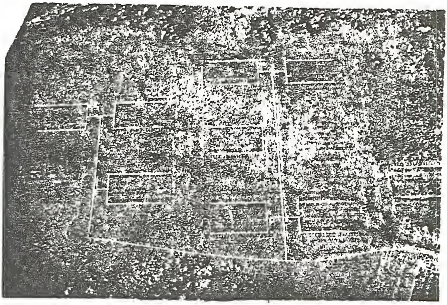

Figure 1. The irrigation system at the *Agropyron smithii* site.

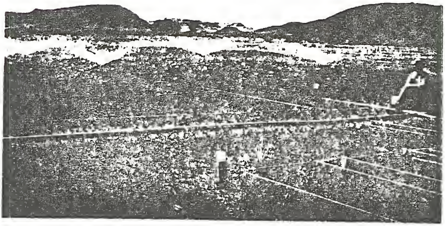

Figure 2. Tom Zuelke irrigating a wet plot at the *Bouteloua gracilis* site.

Table 1. Monthly precipitation (mm) at the *Agropyron smithii* site in 1977. Water supplements are included in the figures given for irrigated plots. (Values which differ from the control are underlined). The number of natural and sprinkler showers contributing to total precipitation follows the quantity measurement.

Month	Rep.	Control	F. Wet	12mm	6mm	S. Wet	Const. Wet
May	I	66.04-14	66.04-14	66.04-14	66.04-14	114.30-14	106.68-14
	II	66.04-14	66.04-14	66.04-14	66.04-14	114.30-14	127.00-14
June	I	20.32-8	20.32-8	20.32-8	25.40-10	261.62-15	152.40-15
	II	20.32-8	20.32-8	20.32-8	22.86-10	233.68-15	170.18-15
July	I	45.72-11	45.72-11	58.42-11	58.42-13	45.72-11	226.06-17
	II	45.72-11	45.72-11	58.42-11	58.42-13	45.72-11	241.30-17
Aug	I	58.42-13	58.42-13	60.96-13	66.04-14	58.42-13	185.42-16
	II	58.42-13	58.42-13	60.96-13	66.04-14	58.42-13	187.96-16
Sept	I	40.64-6	200.66-9	40.64-6	40.64-6	40.64-6	40.64-6
	II	40.64-6	208.28-9	40.64-6	40.64-6	40.64-6	40.64-6
Oct	I	15.24-5	15.24-5	15.24-5	15.24-5	15.24-5	15.24-5
	II	15.24-5	15.24-5	15.24-5	15.24-5	15.24-5	15.24-5
TOTAL	I	246.38-57	406.40-60	261.62-57	271.78-62	535.94-64	726.44-73
	II	246.38-57	414.02-60	261.62-57	269.24-62	508.00-64	782.32-73

Table 2. Monthly precipitation (mm) at the *Bouteloua gracilis* site in 1977. Water supplements are included in the figures given for irrigated plots. (Values which differ from the control are underlined.) The number of natural and sprinkler showers contributing to total precipitation follows the quantity measurement.

Month	Rep.	Control	F. Wet	12mm	6mm	S. Wet	Const. We
May	I	40.64-13	40.64-13	40.64-13	40.64-13	68.58-13	86.36-13
	II	40.64-13	40.64-13	40.64-13	40.64-13	73.66-13	83.82-1
June	I	12.70-6	12.70-6	12.70-6	17.78-7	226.06-11	157.48-10
	II	12.70-6	12.70-6	12.70-6	17.78-7	203.20-11	144.78-10
July	I	35.56-9	35.56-9	48.27-10	50.80-11	35.56-9	185.42-15
	II	35.56-9	35.56-9	45.72-10	48.26-11	35.56-9	182.88-15
Aug	I	33.02-10	33.02-10	35.56-10	38.10-11	33.02-10	114.30-12
	II	33.02-10	33.02-10	35.56-10	38.10-11	33.02-10	116.84-12
Sept	I	45.72-9	231.14-14	45.72-9	45.72-9	45.72-9	45.72-9
	II	45.72-9	231.14-14	45.72-9	45.72-9	45.72-9	45.72-9
Oct	I	25.40-5	25.40-5	25.40-5	25.40-5	25.40-5	25.40-5
	II	25.40-5	25.40-5	25.40-5	25.40-5	25.40-5	25.40-
TOTAL	I	193.04-52	378.46-57	208.29-53	218.44-56	434.34-57	614.68-64
	II	193.04-52	388.62-57	205.75-53	215.90-56	416.56-57	599.44-64

THE RESPONSES

Each response is discussed separately and includes a brief introductory statement, a description of methodology and a summary of the results from the first year.

A. Soil water.

Irrigation of plots is expected to make soil water more available to plants either through addition to the soil water pool or through lower rates of loss from that pool. This of course, is desirable since additional soil water will increase range production.

To measure the effect of the irrigation treatments on soil water availability, soil water potential at depths of 10, 25, and 75 cm were measured with three sets of plaster "Bouyoucos blocks" in each plot at weekly intervals. Some plots were also instrumented with thermocouple psychrometers for comparison.

Results of the plaster block measurements are summarized in Tables A1 and A2. In examining these tables, one should be conscious of the following points. 1) Since the plaster blocks cannot be calibrated accurately for stresses greater than 15 bars, a value of 20 bars was assigned arbitrarily to these stresses. Therefore, stresses over 15 bars are likely to be significantly underestimated. 2) Standard errors among the three sets of blocks in each plot rarely exceeded 1 bar, indicating that soil water concentrations were similar in the center and edges of the treatment plots. 3) Standard errors exceeding 1 bar were only recorded during weeks when rapid drying or wetting of a soil layer occurred.

Soil water stresses in the control and fall wet *Agropyron smithii* plots rose above 15 bars at all three soil depths between 15 and 20 June 1977. Soil water stresses in the unwatered plots at the *Bouteloua gracilis* site did not reach these stresses until approximately 1 July, probably because the vegetation at the *Bouteloua gracilis* site has less transpiring surface. Soil water stresses above 15 bars at soil depth of 25 cm are believed to eliminate significant plant growth. Therefore, any growth that occurred dur the summer must have been supported by water held in soil layers above 10 cm Soil water stresses were reduced by early fall rain. In the control plots at both sites the wetting front reached a soil depth of 10 cm about 1 September, 25 cm about 1 October, and 75 cm after 1 November.

Soil water stresses in the 6 mm and 12 mm treatment plots were nearly identical to those in the control and fall wet plots. Soil water stresses in the summer shower plots at the *Agropyron smithii* site rose above 15 bars in all layers about 17 June, whereas, soil water stresses in these plots at the *Bouteloua gracilis* site rose above 15 bars slightly later between 20 and 29 June. Again, the difference in the dates of effective exhaustion of soil water was probably due to less transpiring surface at the *Bouteloua gracilis* site. Soil water stresses on these plots were reduced below 10 bars by irrigation, twice at the *Agropyron smithii* site and once at the *Bouteloua gracilis* site. On these occasions, such reductions suggest that the only wat available for growth is in the top 10 cm of the soil. Soil water stresses in summer showers plots at both sites were reduced by early fall rains, the wetti front reaching 10 cm about 1 September, 25 cm about 1 October, and 75 cm after 1 November 1977.

The spring wet plots experienced low water stresses due to weekly waterings through 29 June at the *Agropyron smithii* site and through 25 June at the *Bouteloua gracilis* site. At the *Agropyron smithii* site, water stress

Table A1a. Soil water stress at 10 cm under the six treatments at the *Agropyron smithii* site. Data are soil water potentials in negative bars. Each figure is the average of three values.

Date	Wet		S. Wet[1]		6mm		12mm		F. Wet[1]		Control	
	I	II	I	II	I	II	I	II	I	II	I	II
1 JUN	0	0	0	7	0	0	0	0	0	0	0	0
2 JUN	0	0	0	0	1	1	0	1	0	0	0	2
7 JUN	0	0	0	0	1	1	1	2	0	1	1	2
16 JUN	0	0	0	0	10	10	15	2	12	10	17	18
22 JUN	0	0	0	0	18	20	18	20	18	16	16	20
28 JUN	0	0	0	0	18	20	20	20	20	20	20	20
6 JUL	0	0	0	0	9	14	2	1	14	20	15	11
13 JUL	0	0	1	1	8	10	2	1	20	18	14	11
20 JUL	0	0	8	5	18	20	13	10	20	20	20	20
2 AUG	0	0	16	14	1	1	12	15	17	15	9	11
9 AUG	0	0	20	18	7	0	13	16	17	16	20	20
17 AUG	0	0	20	20	11	9	13	14	20	17	20	17
23 AUG	0	0	20	20	15	13	18	17	14	18	11	17
30 AUG	0	0	1	1	1	0	1	1	0	7	0	1
15 SEP	1	0	20	0	3	3	2	9	1	6	1	3
26 SEP	1	1	20	20	15	17	16	20	8	18	5	18
12 OCT	0	0	0	1	1	0	1	1	0	1	0	1
25 OCT	0	0	0	1	1	1	1	1	0	1	1	1

[1] Spring and Fall Wet.

Table Alb. Soil water stress at 25 cm under the six treatments at the *Agropyron smithii* site. Data are soil water potentials in negative bars. Each figure is the average of three valu[illegible]

Date	Wet		S.Wet[1]		6mm		12mm		F.Wet[1]		Control	
	I	II	I	II	I	II	I	II	I	II	I	II
1 JUN	0	0	0	0	0	0	0	0	0	0	0	0
2 JUN	0	0	0	0	4	5	3	2	0	2	2	2
7 JUN	0	0	0	0	6	6	4	3	0	3	3	3
16 JUN	0	0	0	0	13	18	20	15	12	11	20	14
22 JUN	0	0	0	0	20	20	20	20	18	18	16	20
28 JUN	0	0	0	0	20	20	20	20	20	20	20	20
6 JUL	0	0	0	0	20	20	20	20	20	20	20	20
13 JUL	0	0	0	0	20	20	20	18	20	20	20	20
20 JUL	0	0	1	1	20	20	20	18	20	20	20	20
2 AUG	0	0	13	14	20	20	20	20	20	20	20	20
9 AUG	0	0	20	20	20	20	20	20	20	20	20	20
17 AUG	0	0	20	20	20	20	20	20	20	20	20	[illegible]
23 AUG	0	0	20	20	20	20	20	20	20	20	20	20
30 AUG	0	0	20	8	20	20	20	15	20	20	20	20
15 SEP	0	0	20	20	20	20	20	20	9	20	20	20
26 SEP	0	0	20	20	20	20	20	20	10	20	20	20
12 OCT	0	0	7	4	7	0	2	1	0	0	0	1
25 OCT	0	0	5	1	7	0	1	1	0	0	0	1

---

[1] Spring and Fall Wet.

Table A1c. Soil water stress at 75 cm under the six treatments at the *Agropyron smithii* site. Data are soil water potentials in negative bars. Each figure is the average of three values.

Date	Wet		S.Wet[1]		6mm		12mm		F. Wet[1]		Control	
	I	II	I	II	I	II	I	II	I	II	I	II
1 JUN	10	5	10	12	0	0	0	0	0	0	0	0
2 JUN	7	1	11	12	13	10	7	12	0	12	8	9
7 JUN	7	0	5	9	16	12	10	10	0	14	9	11
16 JUN	5	0	3	13	20	14	14	18	12	20	16	15
22 JUN	7	0	9	13	20	20	20	20	18	20	15	20
28 JUN	7	0	0	0	20	20	20	20	20	20	16	18
6 JUL	7	0	0	0	20	20	20	20	20	20	18	20
13 JUL	0	0	0	0	14	20	20	20	20	20	18	20
20 JUL	0	0	0	0	20	20	20	20	20	20	20	20
2 AUG	0	0	0	9	20	20	20	20	20	20	20	20
9 AUG	0	0	10	16	20	20	20	20	20	20	20	20
17 AUG	0	0	14	12	20	20	20	20	20	20	20	20
23 AUG	0	0	14	13	20	20	20	20	20	20	20	20
30 AUG	0	0	17	15	20	20	20	20	20	20	20	20
15 SEP	0	0	16	18	20	20	20	20	20	20	20	20
26 SEP	0	0	17	20	20	20	20	20	20	20	20	20
12 OCT	0	0	18	20	20	20	20	20	0	0	20	20
25 OCT	0	0	18	20	20	20	20	20	0	0	20	20

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[1] Spring and Fall Wet.

Table A2a. Soil water stress at 10 cm under the six treatments at the *Bouteloua gracilis* site. Data are soil water potentials in negative bars. Each figure is the average of three values

Date	Wet		S. Wet[1]		6mm		12mm		F. Wet[1]		Control	
	I	II	I	II	I	II	I	II	I	II	I	II
24 MAY	0	0	0	0	3	2	2	2	2	2	3	2
1 JUN	0	0	0	0	0	0	0	0	0	0	0	0
3 JUN	0	0	0	0	1	0	0	0	0	1	0	0
6 JUN	0	0	0	0	1	1	1	1	1	1	1	1
13 JUN	0	0	0	0	1	1	1	4	4	2	1	1
20 JUN	0	0	0	0	11	2	10	13	12	12	5	7
29 JUN	0	0	0	0	20	20	20	20	20	20	20	20
5 JUL	0	0	0	0	20	8	4	14	20	20	20	11
11 JUL	0	0	1	0	17	5	4	7	20	20	20	9
19 JUL	0	0	5	1	20	20	14	20	20	20	20	20
25 JUL	0	0	20	14	20	20	20	20	20	20	20	20
1 AUG	0	0	11	4	6	2	14	17	10	10	20	1
12 AUG	0	0	20	14	18	20	20	20	20	20	20	15
17 AUG	0	0	20	15	20	20	20	20	20	20	20	20
24 AUG	0	0	20	20	20	20	20	20	20	20	20	20
29 AUG	0	0	2	2	3	1	1	1	1	4	3	1
12 SEP	0	0	6	8	1	1	1	1	1	1	20	20
28 SEP	0	0	6	5	1	1	1	1	0	1	3	1
12 OCT	0	0	0	1	0	1	1	1	0	1	1	1
25 OCT	0	0	0	1	1	1	1	1	1	1	1	1

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[1] Spring and Fall Wet.

Table A2b. Soil water stress at 25 cm under the six treatments at the *Bouteloua gracilis* site. Data are soil water potentials in negative bars. Each figure is the average of three values.

Date	Wet		S. Wet[1]		6mm		12mm		F. Wet[1]		Control	
	I	II	I	II	I	II	I	II	I	II	I	II
24 MAY	3	2	2	3	4	4	6	2	2	2	3	2
1 JUN	0	0	0	0	0	0	0	0	0	0	0	0
3 JUN	0	0	0	1	7	5	7	5	6	3	10	4
6 JUN	0	0	0	0	8	5	4	5	7	3	11	9
13 JUN	0	0	0	0	12	9	5	10	11	6	14	10
20 JUN	0	0	0	0	18	16	9	20	18	13	15	17
29 JUN	0	0	0	0	20	20	20	17	20	20	20	18
5 JUL	0	0	0	0	20	20	20	20	20	20	20	20
11 JUL	0	0	0	0	20	20	20	20	20	20	20	20
18 JUL	0	0	1	0	20	20	20	20	20	20	20	20
25 JUL	1	1	10	1	02	20	20	20	20	20	20	20
1 AUG	0	0	18	5	20	20	20	20	20	20	20	20
12 AUG	0	0	20	14	20	20	20	20	20	20	20	20
17 AUG	0	0	20	14	20	20	20	20	20	20	20	20
24 AUG	0	0	20	18	02	20	20	20	20	20	20	20
29 AUG	0	0	20	20	20	20	20	20	20	20	20	20
12 SEP	0	0	20	20	20	20	20	20	20	20	20	20
28 SEP	0	0	20	20	20	20	20	20	0	0	20	17
12 OCT	0	0	0	1	1	0	1	1	0	1	1	0
25 OCT	0	0	1	1	0	0	1	0	0	1	1	0

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[1] Spring and Fall Wet.

Table A2c. Soil water stress at 75 cm under the six treatments at the *Bouteloua gracilis* site. Data are soil water potentials in negative bars. Each figure is the average of three v

Date	Wet		S. Wet[1]		6mm		12mm		F. Wet[1]		Control	
	I	II	I	II	I	II	I	II	I	II	I	II
24 MAY	5	3	2	3	4	4	6	4	3	2	3	4
1 JUN	8	6	6	7	0	0	0	0	0	0	0	0
3 JUN	9	6	6	8	12	9	14	11	6	5	6	11
6 JUN	10	7	7	9	13	10	16	13	8	6	6	15
13 JUN	7	2	9	7	16	12	20	18	10	9	9	16
20 JUN	9	0	7	7	20	15	20	18	12	13	13	20
29 JUN	0	1	0	0	18	20	20	20	15	15	20	18
5 JUL	0	0	0	0	20	20	20	20	20	20	18	20
11 JUL	0	0	0	0	20	20	20	20	20	18	20	20
18 JUL	0	0	0	0	20	20	20	20	20	20	20	20
25 JUL	0	0	0	0	20	20	20	20	20	20	20	20
1 AUG	0	0	0	0	20	20	20	20	20	20	20	20
12 AUG	0	0	5	2	20	20	20	20	20	20	20	[illegible]
17 AUG	0	0	8	6	20	20	20	20	20	20	20	20
24 AUG	0	0	13	14	20	20	20	20	20	20	20	20
29 AUG	0	0	15	14	20	20	20	20	20	20	20	20
12 SEP	0	0	16	12	20	20	20	20	20	20	20	20
28 SEP	0	0	20	17	20	20	20	20	0	0	20	20
12 OCT	0	0	20	17	20	20	20	20	0	0	20	20
25 OCT	0	0	20	18	20	20	20	20	0	0	20	20

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[1] Spring and Fall Wet.

in these plots rose above 15 bars at the 10 and 25 cm depths on 2 August and at the 75 cm depth on 30 August. At the *Bouteloua gracilis* site water stresses rose above 15 bars at the 10 and 25 cm depths about 12 August, and at the 75 cm depth about 28 September. Water in the active root zone (represented by the 10 and 25 cm plaster blocks) was exhausted in about 45 days at the *Agropyron smithii* site and about 50 days at the *Bouteloua gracilis* site. Again, the faster rates of water loss at the *Agropyron smithii* site were controlled by the larger leaf area.

Soils in the constantly wet plots at both sites never experienced water stresses greater than 1 bar at soil depths of 10 and 25 cm. The wetting front did not reach 75 cm level in these treatments until late June. This is of little concern, since plants obtain most of the available water from surface horizons.

B. Nutrient availability.

Irrigation or supplemental precipitation might change the availability of nutrients for plants in several ways. Nutrient availability might be reduced if leaching rates increased significantly. In contrast, more nutrients might become available if decomposing organisms released nutrients faster than plants are capable of absorbing them, or if nutrients were added to the system by weathering of rock or by increasing populations of nitrogen fixing organisms.

To record changes in nutrient availability through time, soils are being sampled twice annually, first during spring green-up when available nutrients may be plentiful and second during maximum standing crop when soil nutrients may be least available. Last spring, five soil cores were taken between 26 April and 6 May from each of the twelve plots and pooled by plot on the assumption that the study area was uniform and that twelve pooled samples would provide a suitable measure of variation. Four samples were also taken in each of the six treatments (two per plot) between 22-23 August [illegible]9 Each sample consisted of three soil cores taken from clipped strips and pooled so nutrient contents of clipped plants can be related to the soils below. Before pooling, each core was divided into 0-10, 10-30, 30-50, and 50-100 cm horizons. Soils were dried immediately and are being stored.

Nutrients are being analyzed by the Montana State University soil testing laboratory and the results are not yet available.

C. Plant water potential.

Plant water potential controls stomatal opening and photosynthetic rates and is a sensitive indicator of how plants perceive the availability of soil water. Additions to soil water should reduce plant water stress.

Plant water potentials were measured with a "Scholander Pressure Bomb" on two different time schedules during the growing season. All plots were measured on a weekly basis at "dawn" (six to seven o'clock, a.m., MDT) when water stresses are usually lowest and most stable, to determine which irrigation treatments resulted in reducing water stress. Because water stress rises rapidly at sunrise, however, sampling one plot later than another was avoided by measuring randomly the water potential of one stem from each of the twelve plots and then repeating the procedure five times. The results are presented in Table C1. Measurements were also taken at six o'clock a.m., nine o'clock a.m., twelve o'clock noon, three o'clock p.m. and six o'clock p.m. on 31 May, 3 August and 1 September at the *Bouteloua gracilis* site and 24 May, 24 June, 27 July and 19 August at the *Agropyron smithii* site since water stresses fluctuate dramatically each day. Water stresses are usually lowest at dawn because at night, absorption of water through the roots is rapid relative to transpiration but as the sun rises, water is lost faster from the plant via transpiration than that absorbed through the roots. Therefore, water potential was measured first from five stems in one treatment before proceeding to the next treatment. About 8 to 10 minutes was required to measure the water potential in each treatment.

Table C1. A comparison of dawn plant water potential between plots for the six treatments showing the percentage of all readings taken during the season which were less than the stress indicated; thirteen readings were taken at the *Agropyron smithii* site and fourteen readings were taken at the *Bouteloua gracilis* site. Underlined figures probably differ significantly from the control.

plant	plant-water potential (bars)	Control	Fall Wet	12mm	6mm	Spring wet	Constant wet
AGSM	<10	62	54	62	62	92	99
	<20	69	69	69	77	99	99
	<40	77	92	85	77	99	99
BOGR	<10	14	14	14	14	57	79
	<20	36	29	36	36	99	99
	<40	64	64	57	71	99	99

Figure C1 shows that dawn plant water stresses on the control and fall wet plots at the *Agropyron smithii* site were low in early June, rose to high levels by mid June, were relieved slightly after summer showers yielded approximately 12 mm of rain, and finally reduced by showers in August. Dawn water stresses at the control and fall wet plots at the *Bouteloua gracilis* site followed a similar pattern except that the plants were apparently unable to respond to the late August rains--perhaps because they were dormant (Fig. C2).

At both sites, dawn plant water potentials in the 6 mm and 12 mm plots were essentially identical to those observed on the control plots

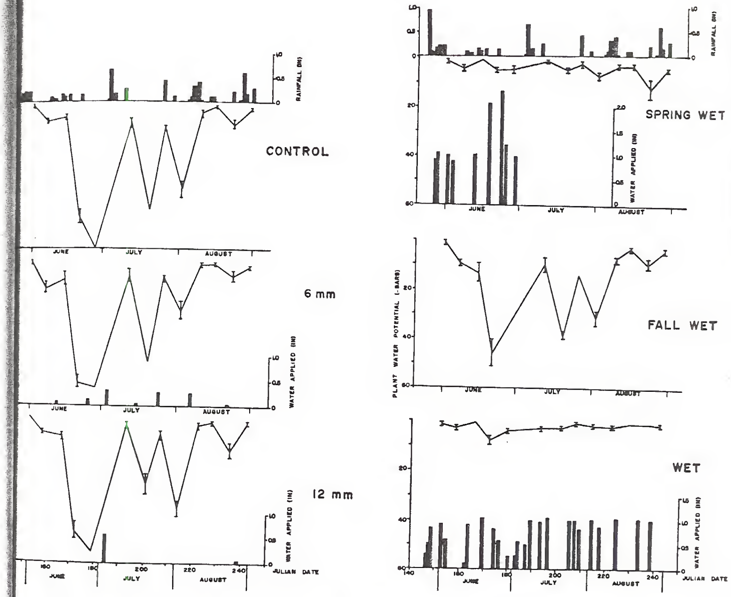
(Fig. C1 and C2). Additional data will be needed to determine whether th slight relief of stress on the 6 mm and 12 mm plots is statistically [illegible] biologically different from the control plots.

Dawn plant water potentials stayed relatively low (less than 20 bars) on the spring wet plots (Fig. C1 and C2). The fact that plant water stresses in the spring wet plots stayed low after soil water in the top 75 cm of the soil was exhausted seems to suggest that water was probably drawn from lower soil layers.

The daily trends of plant water stresses in figure C3 show that the stresses of *Bouteloua gracilis* were generally greater in the afternoon tha at 7 a.m. When soil water was in adequate supply as on 31 May, plant water stresses did not differ significantly between treatments. On 3 Aug however, water stresses differed markedly between the wet and control plots The interpretation of the diurnal pattern observed on 1 September is not clear and additional data will be needed in 1978. Since standard err[illegible] are not available for some water potentials greater than 60 bars, it is impossible to determine statistically the difference between the control and 6 mm treatments. This occurred because the nitrogen supply became too low for the pressure bomb to read the extremely high water potentials. During the summer of 1978 a second full nitrogen bottle will be available.

If water stresses during most of the summer are too great for significa photosynthesis, it becomes important for us to continue efforts to determin 1) the accuracy of the pressure bomb to measure water stresses, 2) at what stresses stomata close, 3) how photosynthesis is related to water stress, and 4) how plants respond to different size showers, *i.e.* how fast can these species turn on growth and how long can they continue growing. (A study is planned for the summer of 1978 to correlate photosynthesis with plant water potential).

AGROPYRON SMITHII SITE 1977



ure C1. Seasonal trend in 'dawn' plant water potentials at the *Agropyron smithii* e. The six treatments are labeled at the right; water supplements, when given, indicated by bars below.

DAWN PLANT WATER POTENTIAL READINGS
BOUTELOUA GRACILIS SITE 1977

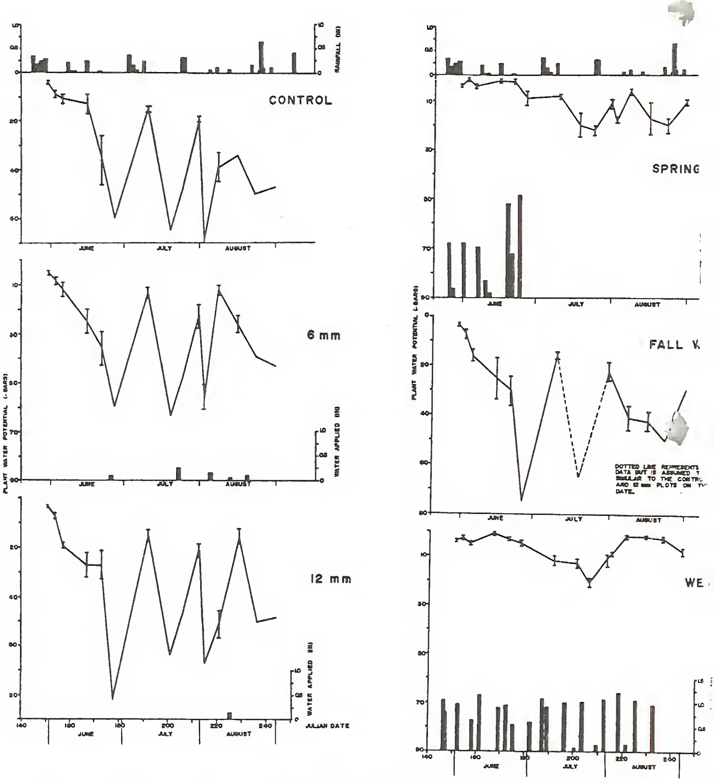


Figure C2. Seasonal trend in 'dawn' plant water potential at the *Bouteloua graci* site. Six treatments are labeled at the right; water supplements, when given, are indicated by bars below.

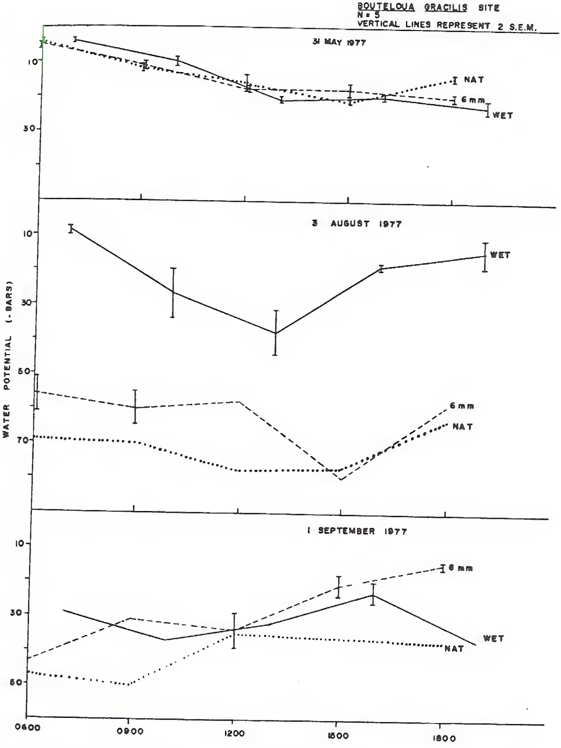


Figure C3. The daily trend in plant water potential at the *Bouteloua gracilis* site: 31 May, 3 August, and 1 September.

D. Plant phenology.

If soil water is increased by irrigation, plants should stay green an[illegible] flower longer during the summer months.

To determine whether the phenologies of *Agropyron smithii* and *Bouteloua gracilis* were affected by the different treatments, both the percentage of plant material which was green on 0.6 x 2.4 m plots and the average flowerin stage of plants in these plots were recorded at weekly intervals. The estimation of greenness of vegetation at both sites proved, however, to be too subjective. In the coming year, standard Munsell color charts will be used to remove this source of subjectivity. In addition, the timing of flowering of all other plant species in each treatment was recorded weekly to determine whether their phenology was also affected by the treatments.

Flowering stages were difficult to record at the *Agropyron smithii* site but were reasonably easy to estimate at the *Bouteloua gracilis* site. At the *Agropyron smithii* site, the flower heads were so few and so irreg[illegible]rl distributed that in 1978 larger plots and/or marked plants will be used to improve our records. Even the dry plots at the *Bouteloua gracilis* site, however, contained many flowers.

The data from the *Bouteloua gracilis* site (Table D1) suggest that flowering may have been hastened by the additional water (e.g. the spring wet and constantly wet plots flowered by 8 June) while drying of heads may have occurred first on the unwatered plots (e.g. the heads of the control and 6 mm plots dried by 21 June).

The early flowering of *Bouteloua gracilis* is surprising since flowering is usually controlled by temperature and day-length. The early browning with limited seed production by about 20 June is well correlated with soil water records which showed that water supplies were exhausted at about [illegible] time. To strengthen our data for statistical analysis at the *Bouteloua gracilis* site, the number of plots will be increased in the spring of 1978 by making them smaller for better control of observations, and by recording the most and least advanced stages instead of trying to estimate an average phenological stage.

Table D1. Phenology of *Bouteloua gracilis* on the six irrigation treatments. A = vegetative, B = in boot, C = green head, D = anthesis, E = green after anthesis, F = brown head shedding seed, G = brown head which probably did not produce germinable seed. August data are identical to July 27.

Month	Day	Control	Fall Wet	12 mm	6 mm	Spring Wet	Constantly Wet
May	24	A	A	A	A	A	A
June	1	A	A	A	A	A	A
	8	BC	BC	BC	BC	C	C
	16	D	D	CD	BD	CD	CD
	21	CG	DG	DG	DG	-	D
July	5	G	EG	EG	EG	E	E
	27	G	FG	FG	FG	F	F

Observation of other species suggests that measuring significant differences statistically during flowering periods will be very difficult because the number of plants available for study (sample size) is too small. For this reason, it appears best to formalize our present nonquantitative measurements. The grasses *Bromus tectorum, bromus japonicus,* and *Poa secunda* are exceptions because they produce many flowers which can be studied by the more rigorous methods and can be compared with the observations of *Bouteloua gracilis*.

E. Plant growth.

If soil and plant water stresses are reduced by watering, *Agropyron smithii* and *Bouteloua gracilis* are expected to grow better.

For this reason, leaf elongation, leaf initiation, and culm initiation are being measured in the control, 6 mm, and wet plots. Leaf initation was determined by counting the leaves present on 20 permanently marked stems in each treatment at weekly intervals. Plant elongation was recorded as the total elongation of the uppermost three leaves since the lower leaves showed little elongation. Elongation was measured as the difference each week between the tip of a leaf and the top of the sheath of the leaf immediately below it, as described in Figure E1. Elongation figures, therefore, include both culm and leaf growth. *Agropyron smithii* culm initiation was measured fortnightly by counting the numbers of culms in ten permanent 9 x 30 cm plots in each treatment. Because *Bouteloua gracilis* clums (flowering and vegetative) are so numerous on a unit area basis, basal area is being estimated yearly on each July 15 as a way of determining whether and when the *Bouteloua gracilis* stand is thickening. This measurement is described in section J2. Basal area data have not yet been summariz

Table E1 shows that leaf numbers increased continuously throughout the summer on the control, 6 mm, and continuously wet plots at the *Agropyron smithii* site. The rates of increase, however, were slower in the control plots than in the other two plots. Leaf numbers averaged 6.4, 7.5, and 11.2 leaves on 1 September in the control, 6 mm, and wet plots, respectively.

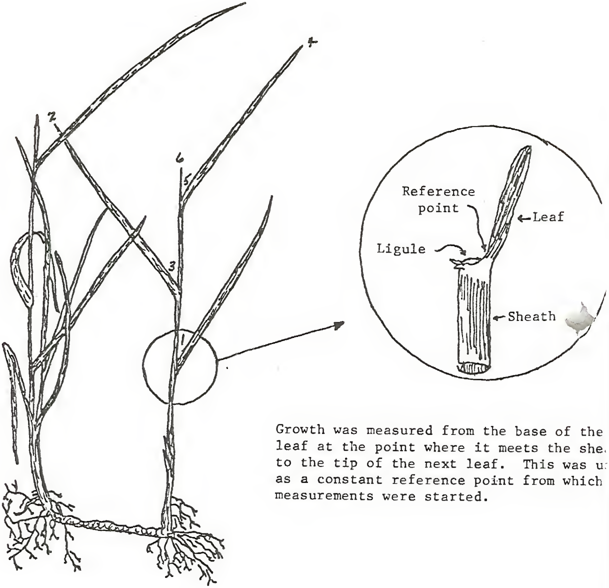
The newly initiated leaves, also, elongated more rapidly on the irrigated plots than on the control plot at both sites (Fig. E2 and E3). The incomplet data at the *Bouteloua gracilis* site is due to loss of plants by grasshoppers. Poisoning should prevent a recurrence of this problem in future years.

Table E1. Mean leaf numbers (±SD) from three treatments at the *Agropyron smithii* site - 1977.

	Treatment		
Date	Control	6mm	Wet
May 24	4.25 ± 0.64	4.35 ± 0.59	4.70 ± 0.80
Jun 1	5.00 ± 0.73	4.80 ± 0.83	5.10 ± 0.30
Jun 7	5.40 ± 0.75	5.30 ± 0.70	5.95 ± 0.60
Jun 15	5.40 ± 0.75	5.35 ± 0.75	6.80 ± 0.52
Jun 21	------	------	7.10 ± 0.72
Jun 24	5.40 ± 0.75	5.32 ± 0.75	------
Jun 28	------	------	7.95 ± 0.51
Jul 5	5.45 ± 0.76	5.42 ± 0.77	8.25 ± 0.79
Jul 12	5.70 ± 0.86	6.11 ± 0.81	8.95 ± 0.89
Jul 19	5.75 ± 0.91	6.32 ± 0.82	9.40 ± 1.05
Jul 26	5.80 ± 0.95	6.42 ± 0.84	9.85 ± 0.93
Aug 2	6.00 ± 0.97	6.53 ± 0.84	10.10 ± 1.12
Aug 10	6.05 ± 0.89	6.89 ± 1.05	10.70 ± 1.22
Aug 16	6.15 ± 0.93	7.21 ± 1.13	10.75 ± 1.21
Aug 25	6.15 ± 0.93	7.37 ± 1.16	10.95 ± 1.28
Aug 30	6.35 ± 1.09	7.47 ± 1.17	11.2 ±1.47

The leaf elongation data further indicate that plant growth on the wet plots decreased at both sites as the season progressed (Fig. E2 and E3). These growth rates dropped markedly in late June at the *Agropyron smithii* site and early August at the *Bouteloua gracilis* site. This suggests that plants respond less to water with leaf growth as the growing season progresses. This conclusion may be false if the decline in growth is due to a maturation of the grasses which could be prevented by constant grazing.

Leaf growth rates on the control and 6 mm plots were reduced drastically



Growth was measured from the base of the leaf at the point where it meets the she to the tip of the next leaf. This was u as a constant reference point from which measurements were started.

Figure E1. Beginning and ending points for growth measurements in *Agropyron smithii*.

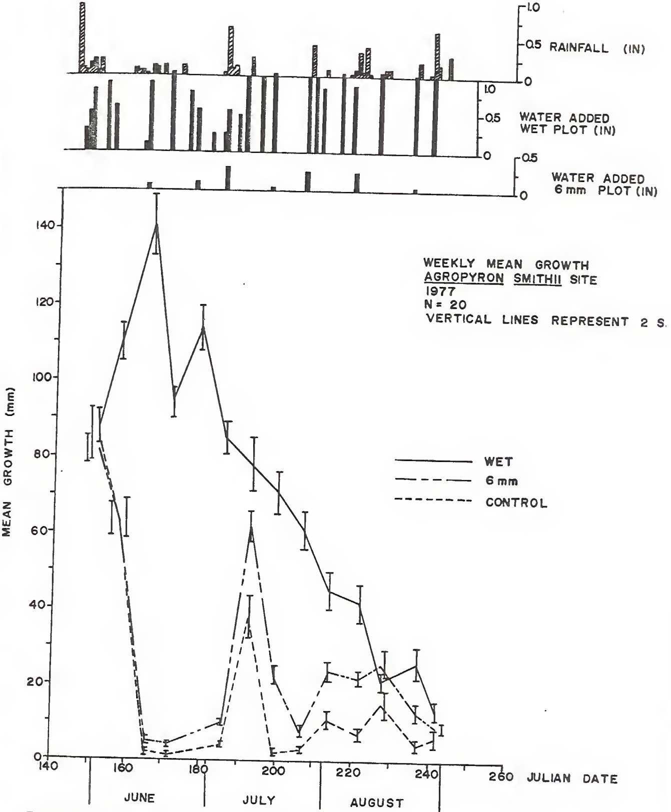


Figure E2. Leaf growth rate (mm/week) of *Agropyron smithii* plants in the constantly wet, 6mm, and control plots. Rainfall data are provided to allow one to relate growth rates to precipitation events.

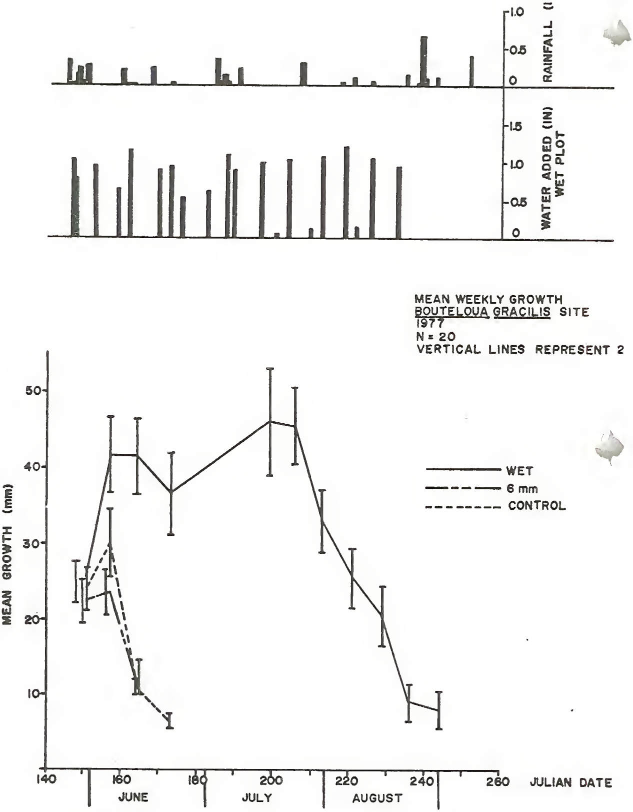


Figure E3. Leaf growth rate (mm/week) of *Bouteloua graclis* in the constantly wet, 6mm, and control plots. Rainfall data are provided to allow one to relate leaf growth to precipitation events.

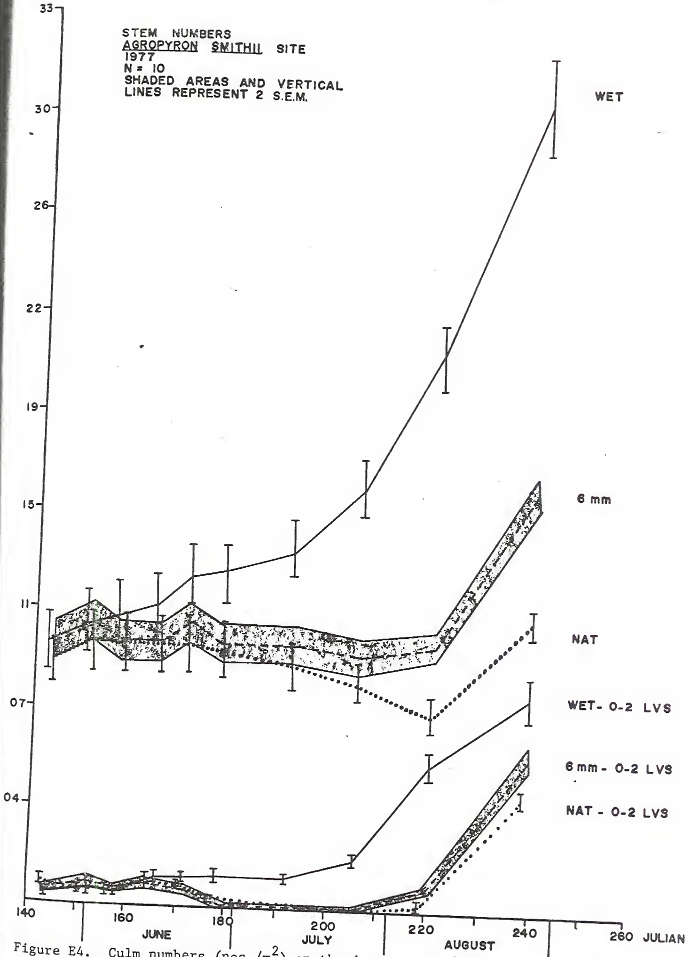


Figure E4. Culm numbers (nos./m^2) on the *Agropyron smithii* site. Data for total culms and new culms with only 0-2 leaves are present.

at both sites in mid June (day 160) when soil water stresses rose above 15 l (Figure E2 and E3). The *Agropyron smithii* plants did respond, however, to 12 mm showers occurring on about 29 June (day 180) and 29 July (day 210). The response to the second shower, however, was much less than to the first-either because the second shower was lighter (it was followed, however, by several more 12 mm showers) or because the plants were less able to respond as the season progressed. If the latter factor is limiting, it becomes important to know whether the seasonal effect (or maturity) might be reduced by grazing or whether it is determiend by day-length (Forcella and Weaver, -reported in 1976 annual report on Montana's Involvement in the High Plains Experiment). The response to summer showers appears to have occurred about five days after the shower. Forcella's data also suggest that the plants require at least three days to respond to rewatering. The data from the control and 6 mm sites may suggest that there was little to no leaf growth response to showers supplying less than 6 mm of rainfall.

While the capacity for leaf growth apparently declines with the advancing season, the capacity to produce new culms increases. *Agropyron smithii* data in Figure E4 illustrate this point. Culm production in all plots began to increase about 1 August (day 213), when leaf growth was declining.

F1. Forage production.

Forage production should increase with additional rainfall because wate is usually thought to be the principal limiting factor in semi-arid rangelan Because nitrogen is also limiting on these ranges, however, a response to a greater availability of nitrogen may be expected.

Grass production was measured in the six treatments with two technique 1) Plants were clipped at a height of 1 cm from one quadrant (0.3 x 0.6 m) chosen randomly in each of the ten strips in each treatment at monthly intervals. The plants were dried to constant weight, and weighed to nearest 0.1 gram. 2) The rate of growth was recorded in more detail by measuring weekly standing crops with a capacitance meter (figure F1). Capacitance meter readings and clippings were made in the same plots so that these data sets could be compared to each other by regression.

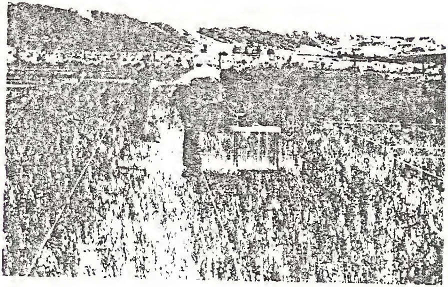


Figure F1. Jeff Birkby, graduate student, calibrating capacitance meter.

To determine whether nitrogen limits production, one strip in each plot at both sites was fertilized with 100 kg/ha of nitrogen in the form of ammonium nitrate. The production responses to the different water treatments and nitrogen could not be measured by clipping because the area available for this experiment was small. Therefore, the response was measured weekly during the growing season with a capacitance meter. At the end of the growing sea 14-17 November, 1977, these plots were clipped at a height of 10 cm, and [illegible] different production responses were compared.

Clipping data from the unfertilized strips throughout the growing season are summarized in Table F1 and F2. Capacitance meter data and the year-end clip data are still being analyzed.

Tables F1 and F2 show that *Agropyron smithii* site is generally more productive than the *Bouteloua gracilis* site. With no supplemental precipitation as in the control plots, maximum standing crops, which comprised approximately 80% of total production, were 68 gm/m^2 at the *Agropyron smithii* site and 22 gm/m^2 at the *Bouteloua gracilis* site. When water was not a limiting factor, as in the wet plots, maximum standing crops were 266 gm/m^2 at the *Agropyron smithii* site and 143 gm/m^2 at the *Bouteloua gracilis* site. One might tentatively conclude that the *Bouteloua gracilis* site made better use of additional water, since without supplemental wat[illegible] this site produced 32% as much as the *Agropyron smithii* site and with unlimited water the *Bouteloua gracilis* site produced 54% as much as the *Agropyron smithii* site.

Production responses to 6 mm and 12 mm treatments were small or nonexistent, while significant responses to large water additions are evident. This can be illustrated with *Agropyron smithii* data, by comparing maximum standing crops in the control and fall wet plots (68 and 74 gm/m^2 respectivel with those of the 6 mm and 12 mm plots (75 and 93 gm/m^2 respectively) and tho of the spring wet and constantly wet plots (265 and 266 gm/m^2 respectively). At the *Bouteloua gracilis* comparable figures are 22-27 gm/m^2 in the control and fall wet treatments, 33-27 gm/m^2 in the 6 mm and 12 mm plots, and 108-142 gm/m^2 in the spring wet and constantly wet plots.

Table F1. Aboveground standing crop under six treatments for the *Agropyron smithii* site. The mean of 10 weights is given in gms/m^2.

Date	Control	6mm	12mm	Fall wet	Spring wet	Wet
24 May	50	57	52	55	55	52
23 May	68	69	93	74	136	150
23 July	63	69	77	65	241	236
18 Aug.	66	75	81	64	265	249
10 Nov.	57	58	61	59	177	266

Table F2. Aboveground standing crop under six treatments for the *Bouteloua gracilis* site. The mean of 10 weights is given in gms/m^2.

Date	Control	6mm	12mm	Fall wet	Spring wet	Wet
31 May	22	33	27	27	28	33
1 July	13	15	12	12	56	48
28 July	11	19	13	14	81	99
25 Aug.	12	17	16	12	108	143
10 Nov.	19	16	16	13	86	111

Additional water did extend slightly the growing season at both sites. At the *Agropyron smithii* site, maximum standing crops were obtained on 23 June in the control, 12 mm and fall wet plots, (essentially unwatered plots); on 18 August in a plot receiving several light supplements (6 mm plots); on 18 August in plots receiving large supplements (spring wet) and on 10 November in the constantly wet plots. Comparable data for the *Bouteloua gracilis* site show that on plots receiving little irrigation water (control, 6 mm and 12 mm, and fall wet) maximum standing crops were achieved by 31 May while plots receiving significant supplements (spring wet and constantly wet) achieved maximum standing crops later in August. Maximum standing crop may be early on the drier plots at the *Bouteloua gracilis* site, however, due to grasshopper infestation.

Maximum standing crops on ungrazed sites might be expected to be achieved at about the time growth halts. Wet plot data suggest that *Bouteloua gracilis* growth will halt about 1 September regardless of water supplements while *Agropyron smithii* may continue to grow in the fall (Table F3). Spring wet plot data suggest that growth may continue for about two weeks after apparent exhaustion of soil water; this growth is more than likely supported by water found at soil depths below 25 cm at the *Bouteloua gracilis* site and below our soil water sensors at the *Agropyron smithii* site.

Data from the 12 mm plots suggest that little or no important production response is generated by one or two light showers occurring after the soil profile is apparently dry, while data from the 6 mm plots suggest that *Agropyron smithii* (but not *Bouteloua gracilis*) may respond to summer showers. Data from the control and fall wet plots suggest that little growth can occur after the soil profile is apparently empty.

Table F3. Approximate dates of soil water exhaustion and maximum standing crop in plots receiving the six irrigation treatments at the *Agropyron smithii* and *Bouteloua gracilis* sites. Number of asterisks indicates the number of rains which wet soils to 10 cm after the root zone had initially dried.

Treatment	Water exhausted		Maximum standing crop	
	Agropyron	*Bouteloua*	*Agropyron*	*Bouteloua*
Control	16 June	29 June	23 June	31 May
fall wet	22 June	29 June	23 June	31 May
12mm	16 June**	29 June*	23 June	31 May
6mm	22 June**	29 June*	18 August	31 May
Spr. wet	2 August	12 August	18 August	25 August
constant wet	never	never	10 November	25 August

F2. Effects of single waterings on forage production.

Our basic experiment was designed to determine the effects of regular patterns of rainfall on vegetation. It will not answer, however, two relevant questions: 1) what are the relative effects of a single large shower in early, middle or late summer? and 2) if grasses do not respond well to a light shower in late summer, is it because the shower was too light or because the grasses were dormant?

To answer these questions, the following experiment was initiated. Small plots at the *Agropyron smithii* were irrigated on 28 July, 23 August, and 26 September until soils at 25 cm were saturated with water. Production responses on these irrigated plots were contrasted to those on unwatered control plots. Comparisons were made with the capacitance meter and with a late fall clip on 10 November. Methods were identical to those used in the principal production experiment.

Table F4. Maximum standing crops on an unwatered plot and plots watered to field capacity at 25cm at the *Agropyron* site on the dates in[illegible]a

Date	28 July	23 August	26 September	unwatered (control)
Maximum standing crop (gms/m^2)	138	104	59	57

Table F4 shows that the *Agropyron smithii* grassland responded quickly in July and August but not in September. Water applied in September may stimulate a fall greening and/or may be stored for use in the coming season.

The production responses were much greater from the early than the late watering. The late July watering increased production by 81 gm/m^2 (134%), the late August watering increased production by 45 gm/m^2 (76%), and the late September watering increased production by 2 gm/m^2 (4%).

G. Forage Quality

Protein content of plant material may decrease if steminess increases with increased water. There could also be a simultaneous increase in total aboveground nitrogen if the added water results in increased decomposition rates coupled with an increased nitrogen uptake by plants.

To determine the magnitude of these effects, the nitrogen content of grasses clipped in June, July, August, September, and November will be analyzed by the Montana State University Chemistry Department. Excess sample material will be saved for other determinations such as lipid content, carbohydrate content, digestibility, etc.

H. Seed Production.

Additions of water might increase seed as well as foliage production. To test this hypothesis, the number of flowering culms were counted and will b or have been multiplied by the estimated weight of each culm to measure reproductive effort and by the estimated weight of seed heads to provide an index of seed yield. The number of maturing heads was counted on 7 July 1977 in each of twenty-two 0.3 x 0.6 m capacitance meter plots in the fertilized and unfertilized strips at both sites. Because *Agropyron smithii* heads were few, they were also counted in a larger sample area in the five clip strips- 64.1 m^2- on 1 September. On August 7, when heads of both species were mature, the culm nearest to the diagonal corners of each 0.3 x 0.6 m capacitance meter plot was collected to represent the culms and their weights in these strips. These culms were pressed and dried for later study. Average culm and spike weights have been determined as indices of reproductive effort and seed yield. Seed numbers and germination rates may also be contrasted across plots. Some of the results are presented herein.

Table H1 indicates that irrigation of an *Agropyron smithii* grassland had little effect on numbers of flowering culms produced. These data may weakly suggest that flowering culms were more numerous in wet and spring wet plots than in treatments receiving less water although the differences are not statistically significant. (The patchiness of flowering in *Agropyron smithii* and the resultant difficulty of sampling are well known to range managers.) If culm numbers were equal but culms in wet plots bore more seeds, than seed yields would be higher on watered than on unwatered plots. Field observation suggests that this is the case, but we did not sample culms since the removal of a large proportion of the sparse flowering culms might have altered future reproduction.

Irrigation of the *Bouteloua gracilis* grassland, however, clearly increased reproductive effort and seed yield (Table H2). The average reproductive effort, including both culms and spikes, on the wet and spring wet

Table H1. Numbers of flowering culms on an *Agropyron smithii* grassland for the six treatments. Mean numbers per square meter are presented.

Treatment	Rep.	Unfertilized 6 Jul	Unfertilized 1 Sep	Fertilized 6 July
wet	I	1.0	1.9	3.7
	II	2.9	1.1	1.0
spring wet	I	3.2	2.6	6.3
	II	8.5	4.7	3.7
6mm	I	0.5	0.8	1.0
	II	1.2	1.0	1.2
12mm	I	2.2	1.1	0.2
	II	2.0	1.4	1.0
fall wet	I	1.7	1.3	3.4
	II	0.2	0.3	0.7
control	I	0.2	0.5	0.0
	II	0.2	0.7	0.0

Table H2. Reproductive production on a *Bouteloua gracilis* grassland for the six treatments. Culm weight (including spikes) per square meter is presented as an index of total reproductive effort. Spike weight (gm/m^2) is presented as an index of seed production. No measure of rhizome growth is given.

Treatment	Rep	Unfertilized culms/m^2	Unfertilized culm wt	Unfertilized spike wt	Fertilized culms/m^2	Fertilized culm wt	Fertilized spike wt
wet	I	307	49	9	705	92	20
	II	317	35	8	829	108	22
spr. wet	I	430	65	12	646	65	14
	II	274	25	5	839	134	23
6mm	I	161	11	3	145	10	3
	II	97	5	1	204	12	3
12mm	I	135	10	2	215	15	4
	II	102	6	1	167	10	3
fall wet	I	124	7	2	102	6	2
	II	91	5	1	156	9	3
control	I	27	1	0	102	6	2
	II	48	2	1	75	5	1

plots was 43 gm/m^2 (100 gm/m^2 on plots receiving 100 kg/ha of nitrogen fertilizer), while that on plots receiving little water was 7 gm/m^2 (9 gm/m^2 with nitrogen fertilization). The average spike production was 8 gm/m^2 (20 gm/m^2 with nitrogen fertilization) on wet and spring wet plots while that on plots receiving little water was 1 gm/m^2 (2 gm/m^2 with nitrogen fertilization) Spike weight is a good index of seed production even though it probably over estimates the seeds produced because nonseed material is included, but probably underestimates the differences between treatments because more seeds seem to shatter out of the more robust spikes produced on the wetter plots.

Data gathered for *Bouteloua gracilis* but not presented in this report, show that: 1) weights of culms with spikes removed were almost twice as heavy on wet plots (average = 0.1 gm each) than on dry plots (average = 0.04 gm each), 2) numbers of spikes per culm (average = 1.72 with few culms having more than two spikes) did not increase with increased water, and 3) despite more apparent shattering, spikes weights on wet plots (average wt. = 0.02 gm) were greater than those on dry plots (average wt. = 0.01 gm).

I. Root biomass and root-shoot ratios.

When water is available, plants will need relatively few roots to satisfy their water needs. Therefore, the absolute root biomass (gm/m^2) should not change or increase with supplemental water while the ratio of root to shoot biomass should decline with watering.

To determine the root biomass, roots were extracted from representative soil cores, which were collected from each plot, and ashed. All cores were taken from recently clipped plots. Five cores were taken from each of the twelve plots in April and May and pooled by plot on the assumption that the study area was uniform and that twelve samples would provide a suitable measure of variation. Three sets of five pooled cores were taken from each

each plot in June and July. Two sets of three pooled cores were also taken from each plot in late August. These soil cores were divided into 0-10, 10-30, 30-50, and 50-100 cm horizons. Those samples taken 26 April to 6 May and 22-30 August were collected with a 2 cm diameter King tube while those taken in June and July were collected with a 1.9 cm diameter Oakfield sampler. All cores were soaked in Calgon solution to soften them. Most of the soil was removed by decanting and washing through a 1 mm screen. The remaining soil was removed by ashing the roots and subtracting ash weight from the total root-soil weight. *Agropyron smithii* roots collected in May, June, July and half of August were washed out by A. Schueren; the remaining roots will be washed out by K. Ellingsen.

Table 11 shows that most of the roots were concentrated in the surface layers at both sites. At the *Agropyron smithii* site in early May, for example, the 0-10 cm layer contained 51 gm/m^2, the 10-30 cm layer contained 27 gm/m^2, and the 30-50 cm layer contained 26 gm/m^2. Corresponding figures for the *Bouteloua gracilis* site are 94, 67, 53 gm/m^2. These results show that the initial root biomass at the *Agropyron smithii* site was only half that at the *Bouteloua gracilis* site. This was true despite the fact that aboveground production is normally three times greater on the *Agropyron smithii* site (about 70 gm/m^2) than on the *Bouteloua gracilis* site (about 20 gm/m^2).

Root and shoot biomass apparently increased with season, but irrigation only effected shoot biomass, not root biomass. Data from the *Agropyron smithii* site illustrate these points: 1) both the control and wet plots root biomasses in the 0-30 cm layers doubled between 1 May and 1 August. 2) both initial (41 gm/m^2) and final (92 gm/m^2) root biomasses were identical on the control and wet plots.

The root-shoot ratios decrease with irrigation since root biomass remains

Table I1. Root biomass under *Agropyron smithii* and *Bouteloua gracilis* grasslands for the six treatments. Samples were collected late in the month; actual dates appear in the text.

		Root Biomass (gms/m^2)					
		Agropyron smithii soil depth			*Bouteloua gracilis* soil depth		
Treatment	month	0-10	10-30	30-50 cm	0-10	10-30	30-50 cm
wet	Apr	41	22	25	92	76	54
	Jun	86	69				
	Jul	92	53		78	78	
spr.wet	Apr	64	32	25	80	64	41
	Jun	97	55		106	78	
	Jul	104	70		106	85	
6 mm	Apr	54	32	38	111	67	51
	Jun						
	Jul						
12 mm	Apr	54	19	22	86	64	35
	Jun						
	Jul						
fall wet	Apr	51	19	22	111	73	57
	Jun						
	Jul						
control	Apr	41	19	22	83	57	80
	Jun	87	68		106	76	
	Jul	92	53				

Table I2. Root biomass/shoot biomass at maximum standing crop on an *Agropyron smithii* grassland for the six treatments. All data are expressed in gm/m^2.

treatment	control	fall wet	12mm	6mm	spr. wet	wet
root biomass	100	100	100	100	100	100
shoot biomass	68	74	93	75	264	266
root/shoot ratio	1.47	1.35	1.06	1.33	.38	.38

unchanged while shoot biomass increases. The data most appropriate to illustrate this point will not be available until May or June when the remaining fall root cores have been analyzed. One may, however, illustrate this point first, by assuming that root biomass in the top 50 cm of the soil doubled during the growing season from 50 gm/m^2 to 100 gm/m^2 (cf the previous paragraph) and second, by comparing this figure to maximum standing crops on the different treatments. Such a comparison (Table I2) shows that even if one ignores roots below a depth of 0.5 m, over 60% of the biomass on the control *Agropyron smithii* plots is belowground, while on plots provided with unlimited irrigation water only 27% of the biomass is belowground. An important effect of supplemental water is not only to increase production, but also to increase that production in a sphere where it can be harvested by conventional means.

J. Range composition: species presence.

Range sites with different moisture regimes usually have different compositions. The composition of watered rangeland will change qualitatively and quantitatively.

To record the invasion of the sites by species not presently there, semi-quantitative species lists are being prepared for each plot in early, middle, and late summer (21 May, 13 July, and 31 August in 1977). Species presence was noted in 14 x 14 m plots. Plant numbers were estimated according to the following logarithmic scale so that increases in density of a species which invades and increases markedly over several years can be recorded easily: A = 1 plant per plot, B = 2 to 3, C = 4 to 9, D = 10 to 27, E = 28 to 81, F = 82 to 243, and G = over 243 plants per plot.

At the *Agropyron smithii* site (Table J1), *Euphorbia marginata* and *Helianthus anuus* invaded the spring wet plots. In addition to *Euphorbia*

Table J1. Species at the *Agropyron smithii* site (1977). Presence in a treatment is indicated by a plus or a letter, the first symbol indicates presence in block I while the second indicates presence in block II. A plus indicates presence in phenology records, letters indicate densities as described in the text.

	Control	F. Wet	12mm	6mm	S. Wet	Con. Wet
Agropyron smithii (Western wheatgrass)	GG	GG	GG	GG	GG	GG
Agropyron cristatum (Crested wheatgrass)	CD	CE	DA	BC	CC	EB
Bromus japonicus (Japanese brome)	GG	GG	GG	GG	GG	GG
Stipa comata (Needleandthread)	CE	EE	DE	CE	D.	EE
Poa secunda (Sandburg bluegrass)	+.	.+		.+		++
Tragopogon dubius (Yellow salsify)	.+	.E	.E	+.	AD	CE
Lesquerella ludoviciana (Foothill bladderpod)		.+	.B	+.	.C	+.
Sisymbrium altissimum (Tumbling hedge mustard)	.			+.		
Artemissia frigida (Fringed sagewort)					A.	
Cryptantha bradburiana (Miners candle)	.+					
Spheralcea coccinea (Scarlet globemallow)	.E	A.				
Euphorbia marginata (Snow-on-the-mountain)					AC	CD
Helianthus anuus (Common sunflower)					ED	DE
Melilotus officinalis (Yellow sweetclover)						BF

marginata and *Helianthus anuus, Melilotus officinalis* invaded the wet plots.

At the *Bouteloua gracilis* site (Table J2) *Cryptantha bradburiana, Euphorbia sp.* and *Sporobolus cryptandrous* invaded the spring wet and wet plots Although *Agropyron smithii* is expected to increase with watering, its apparent increase on the wet plots probably indicates an error of sampling rather than a response to irrigation. Since the *Euphorbia* species did not flower last summer, we have not been able to identify them.

J2. Range composition: cover data

Qualitative measures of species composition such as the semi-quantitative species list discussed previously, should record the invasion and disappearance of species from the site. This method, however, may be too coarse to measure water induced changes in cover and biomass of some economically important dominant species.

To record the gradual growth or disappearance of major species, the percentage of the ground covered by each species is being determined by sampling the plants present in eight sets of 43 permanent points (4 sets in each block) in each treatment at least once annually. Samples were taken on 15 July at the *Agropyron smithii* site and on 16 June, 14 July and 11 August at the *Bouteloua gracilis* site.

A computer program for analyzing these data is being prepared.

J3. Range composition: seedling establishment

The rate of change in species composition after initiation of cloud seeding may be quite slow because areas with more rainfall may be separated by many miles of farm land without the appropriate seeds. To eliminate plant migration time and predict the final climax vegetation within the duration of a reasonably short experiment (5-6 years) it was necessary to test the ability

Table J2. Species at the *Bouteloua gracilis* site (1977). Presence is indicated in a treatment by a plus or a letter; the first symbol indicates presence in block I while the second indicates presence in block II. A plus indicates presence in phenology records; letters indicate densities as described in the text.

	Control	F. Wet	12mm	6mm	S.Wet	Con. Wet
Bouteloua gracilis (blue grama)	GG	GG	GG	GG	GG	GG
Bromus tectorum (Cheat grass)	GG	GG	GG	GG	GG	GG
Stipa Comata (Needleandthread)	DC	DE	DD	EC	D.	.D
Buchloe dactaloides (Buffalograss)		.G				
Sphaeralcea coccinea (Scarlet globemallow)	B.	E.	BD		EF	EG
Tragopogon dubinus (Yellow salsify)		+.				
Agropyron smithii (Western wheatgrass)				E.	G.	GG
Euphorbia sp. (Spurge)			B.		FE	EG
Sporobolus cryptandrous (Sand dropseed)				E.	.C	C.
Cryptantha bradburiana (Miners Candle)					B.	B.

of seeds of mesic plants to germinate and become established on the six irrigated plots.

To test this, the following series of important grasses, given in order of increasing water requirements, were selected: *Agropyron dasystachyum* (thickspike wheatgrass), *Stipa viridula* (green needlegrass), *Bromus inermis* (smoothbrome), *Andropogon scoparius* (little bluestem), *Panicum virgatum* (switchgrass panic), *Andropogon gerardii* (big bluestem), and *Sorgastrum nutans* (yellow indiangrass). Two hundred seeds of each species were planted in three 0.3 x 0.5 m plots on each of two replicate sites on 14 May 1977 by first scratching the ground lightly with a hand cultivator, scattering the seeds evenly over the plots, and then tramping the plots thoroughly. The numbers of plants established were recorded on 1 September 1977 and the number of plants surviving at the end of each succeeding summer will be recorded. It may be desirable and possible, to seed new plots in 1979 to record the ability of plants to invade a thickened grassland. The 1977 results appear in Table J3.

Examination of table J3 shows the following: 1) seed establishment was nearly identical on the *Agropyron smithii* and *Bouteloua gracilis* sites, 2) no plants became established in plots receiving no additional water (control and fall wet plots), 3) no plants became established in plots receiving light summer water supplements (6 and 12 mm treatments), and 4) four of seven species planted became established on wet plots and spring wet plots. The species which became established on the wet plots were moisture loving species of the central and eastern plains, specifically *Andropogon scoparius*, *Andropogon gerardii*, *Sorgastrum nutans*, and *Panicum virgatum*. All but *Panicum virgatum* flowered in the wet treatment plots at the *Bouteloua gracilis* site. No species flowered at the *Agropyron smithii* site suggesting more competition in this vegetation type. The failure of *Agropyron dasystachyum, Stipa viridula,* and *Bromus inermis* to become established on any site is surprising. Perhaps the dry plots were too dry and the wet plots were too wet for these species, or perhaps the seeds were planted too late in the spring and will not become established until 1978.

Table J3. Establishment of introduced species on plots receiving different water supplements in *Agropyron smithii* (AGSM) and *Bouteloua gracilis* (BOGR) grasslands. Plant species are listed in order of increasing water requirements; a key to the abbreviations used is provided in the text. The data presented are the percentages of six plots in which the species established.

Plant	Site	Control	F. Wet	12mm	6mm	S. Wet	Wet
AGDA	AGSM	0	0	0	0	0	0
	BOGR	0	0	0	0	0	0
STVI	AGSM	0	0	0	0	0	0
	BOGR	0	0	0	0	0	0
BRIN	AGSM	0	0	0	0	0	0
	BOGR	0	0	0	0	0	0
ANSC	AGSM	0	0	0	0	99	99
	BOGR	0	0	0	0	99	83
PAVI	AGSM	0	0	0	0	99	99
	BOGR	0	0	0	0	99	99
ANGE	AGSM	0	0	0	0	99	99
	BOGR	0	0	0	0	99	83
SONU	AGSM	0	0	0	0	99	99
	BOGR	0	0	0	0	99	99

K. Plant pathogens.

Fungal and bacterial diseases usually increase with additional moisture so they might be expected to be most prevalent in our wettest plots.

To determine the importance of leaf spot bacteria and/or fungi in the six treatments, fifty plants were collected from each treatment late in the summer (30 August - 1 September) and examined for leaf spots. The plants studied were collected objectively by choosing the plant nearest to points located at 20 cm intervals along a ten meter tape stretched through the center of the capacitance meter strip. These plants were pressed immediately for laboratory study and for later comparison with plants to be collected over the next five to six years. Fungal-bacterial leaf spots were analyzed by plant pathologist D. Yount.

Table K1. The effect of irrigation on fungal bacterial attack in *Agropyron smithii* and *Bouteloua gracilis* grasslands, 1977.

Treatment	Rep.	leaf spots/100 leaves		ergot heads/100 heads	
		AGSM	BOGR	AGSM	BOGR
wet	I	9	0	3	0
	II	9	1	24	0
N.Dak	I	11	2	1	0
	II	8	4	13	0
6 mm	I	7	0	0	0
	II	9	2	0	0
12 mm	I	8	1	0	0
	II	12	3	0	0
fall wet	I	13	2	0	0
	II	11	2	0	0
control	I	7	1	0	0
	II	12	6	0	0

Seed heads were also examined for evidence of fungal and/or bacterial attack. Although there was some evidence of smut, ergot was the only seed head fungus which merited recording. Differences in ergot attack levels across treatments were documented by determining the proportion of infested seed heads present in the five clip strips.

Table K1 shows that the numbers of leaf spots per 100 leaves range from 7 to 13 at the *Agropyron smithii* site and from 0 to 6 at the *Bouteloua gracilis* site. There was no increase in numbers of leaf spots with increasing water. This surprising observation might be explained by any of three possibilities. There was no effect of additional precipitation on pathogens. Perhaps the plants in our small plots dried so rapidly that the periods available for infection were abnormally short. It also might be that pathogen populations did not have adequate time to reach epidemic sizes. Further observations will permit firmer conclusions.

Seeds of *Agropyron smithii*--but not *Bouteloua gracilis*--were affected by ergot in the wet treatments. This observation may be economically important because ergot induces abortion in livestock. The reason why the infestation was significantly worse in one replication is not clear--observations in 1978 will tell us whether the difference could have been due to differences in innoculum size.

L. Decomposition

If temperature and oxygen availability were similar on moist and dry plots, decomposition rates would likely be correlated with the number of days of moist soil. Higher decomposition rates should release more nutrients which in turn should increase plant growth.

To contrast relative decomposition rates between treatments, wooden stakes were driven into the ground at 10 cm intervals along a line down the center of one clip strip in each treatment on 16 June 1977. These stakes are being periodically retrieved at the beginning and end of each irrigation season (April and September) to obtain an estimate of the rate of decomposition. Cumulative weight loss will be determined over the next five year period. The stakes were driven vertically into the soil so as not to disturb the site and to index decomposition throughout this most biologically active layer. In the future, it may be desirable to halve the stakes to contrast decomposition rates in the first and second 5 cm soil horizons. The stakes had to be pulled with pliers in the first retrieval (1 Sept 1977), but will be extracted with an Oakfield sampler at future dates to avoid breaking them as decomposition continues to reduce their tensil strength. As decomposition proceeds, it may become increasingly difficult to remove mineral soil (which biases their weight upward) from the stakes. To avoid this problem, the data may be determined on an ash free basis, so all stakes have been saved.

Table L1 shows that decomposition occurred in all treatments during the 1977 summer even though some of the treatments were relatively dry. Decomposition rates in the soils at *Agropyron smithii* site averaged 12% in the wet plots, 8% in the spring wet plots and 3% in the four dry treatments. Losses at the *Bouteloua gracilis* site averaged 11% in the wet plots, 5% in the spring wet plots, and 4% in the four dry treatments.

These results may understate actual differences in decomposition between treatments 1) if larger amounts of soil were held by the more decomposed wet treatment stakes 2) if fungal hyphae were replacing the wood they decomposed or 3) if the relatively thick stakes were decomposing and releasing their nutrients more slowly than the thin roots normally present in grasslands. The first problem can be remedied by ashing the stakes as

Table L1. Mean weights of 10 cm wooden stakes buried vertically for ten weeks in soils receiving different irrigation treatments. Means and standard errors of five samples are given. At installation stakes weighed 1.30± 0.009 gm each.

Treatment	rep.	*Agropyron smithii* site	*Bouteloua gracilis* site
wet	I	1.19±0.04	1.20±0.06
	II	1.11±0.05	1.12±0.03
spr. wet	I	1.19±0.07	1.23±0.02
		1.22±0.04	1.23±0.05
6 mm	I	1.35±0.05	1.27±0.02
	II	1.28±0.03	1.27±0.04
12 mm	I	1.26±0.04	1.29±0.03
	II	1.25±0.03	1.24±0.03
fall wet	I	1.28±0.03	1.21±0.02
	II	1.27±0.03	1.30±0.02
control	I	1.20±0.06	1.12±0.05
	II	1.30±0.06	1.25±0.03

described above. The second problem is not relevant to nutrient release since material incorporated in fungal hyphae is unavailable to plants. The third problem could be remedied by using stakes that are as thin as roots. Suitable techniques may be developed.

M. Insect utilization.

Insect damage might be greater on moist plots than dry plots a) if insect populations thrive on moist plots or b) if greener vegetation were more palatable and attracts insects to the moist plots.

To record the degree of grasshopper damage, the number of chewed areas were counted on leaves of fifty plants collected in each treatment. These plants were collected at points nearest to 20 cm intervals along a 10 m tape strung through the capacitance meter plots. The collection was made late in the season from 30 August to 1 September so as to include the cumulative damage over the entire summer.

Though they may be important, the population sizes and impacts of non-chewing insects (e.g., sucking aphids) and belowground invertebrates (chew or sucking insects, nematodes, etc.) were not recorded. Brent Haglund began developing methods to extract belowground invertebrates. Refer to the 1977 Annual Report by Brent Haglund in which he describes the changes in species composition and numbers of grasshoppers near the two sites throughout the 1977 summer (Appendix II).

Table M1 shows that the damage caused by chewing insects was different at the two sites. At the *Agropyron smithii* site, no difference in insect damage was observed on the watered and unwatered treatments. Chewed spots range from 8 to 24 per 100 leaves and showed no trend along the water gradient. For example, the wet and control plot data were similar. In contrast, more damage was caused by chewing insects in the unwatered plots at the *Bouteloua gracilis* site. Chewed spots per 100 leaves ranged from 17 to 25 in the wet and spring wet plots and from 37 to 50 in plots receiving rainfall supplements of less than 6 mm per week. Similar trends are shown in the data on chewed spots per fifty plants.

Casual observation suggests that the size of leaves increased more rapidly with increased water on both sites than the size of chewed spots. If so, the percentage of total production taken by chewing insects declined with increased water, even though the number of chewed spots per 100 leaves remained constant.

The *Agropyron smithii* site was sprayed with Malathion (2 oz/plot) on 29 July, 1977, and poisoned grain (bran treated with Sevin) was distributed over and around the *Bouteloua gracilis* site on 5 and 21 July, 1977. The results described above, therefore, probably underestimate the amount of damage that would have been done in the absence of insect control at both sit

Table M1. The effect of irrigation on damage done by chewing insects in *Agropyron smithii* and *Bouteloua gracilis* grasslands.

Treatment	Reps	Chewed spots/100 leaves AGSM	Chewed spots/100 leaves BOGR	Chewed spots/50 plants AGSM	Chewed spots/50 plants BOGR
Wet	I	17	24	57	53
	II	9	17	29	45
N. Dak.	I	20	22	66	47
	II	22	25	75	57
6mm	I	16	37	45	72
	II	24	40	60	79
12mm	I	24	48	52	84
	II	26	49	59	94
Constant Wet	I	20	32	37	60
	II	13	43	27	77
Control	I	8	47	15	84
	II	20	50	45	88

DISCUSSION

Drawing conclusions from the first year of a study designed to determine the short and mid-term (six years) effects of a weather modification program is premature at best. Most of our efforts during the first year were devoted to designing the study, to locating and constructing the two experimental sites, to improving the methodology, and to testing the hypotheses. The following discussion, therefore, contains the changes in methodology that will be made in 1978, the new studies which are planned, and our preliminary findings.

Two of the six treatments will be modified slightly in 1978. Rather than guaranteeing 12 mm of water every two weeks on the 12 mm plots, these plots will be guaranteed 12 mm of additional water every week. This change became necessary because the 12 mm treatments only received a total of 15 mm of additional water in 1977. Secondly, the spring wet treatment plots will be changed because this treatment received too much water for too long a time in 1977. Rather than mimicking a Dickinson rainfall regime, a rainfall regime further east was simulated. In 1978, the spring wet plots will be saturated with water only until early June and than allowed to dry.

Two of the experimental approaches will be modified in 1978. Growth will be measured, not just on the wet, control, and 6 mm plots, but also on the 12 mm plots at the *Agropyron smithii* site. Also the single shower experiment will be started earlier in the spring. One or more plots will be soaked each month during the growing season from May through September. These modifications in methodology will be undertaken to determine in what month and how much additional moisture can plants use most efficiently.

Since we are using soil water potential as our independent variable, we must quantify the difference between artificially irrigating a plot from natural rainfall. The difference between the two has been termed "the small plot effect" or "oasis effect." A new graduate student will study this effect beginning in 1978 and he will use lysimetry and measurements of soil water potential and plant water potential on natural and irrigated shower plots.

Brent Haglund, a doctoral student at the Institute of Ecology in Georgia, is studying the effects of additional moisture on aboveground and belowground arthopods, various predators, and decomposers. He plans to take his findings and combine them with the information obtained from this irrigation study to develop a water model which will consist primarily of the interrelationships between precipitation, soil moisture, sucking herbivores, chewing herbivores, predators, decomposer, and primary producers.

A brief discussion of the preliminary findings from the first year are below.

1) Soil moisture will continue to be our independent variable in the coming years and again will be measured both with psychrometers and plaster "Bouyoucos" blocks. The slight discrepancy in the data obtained from the two instruments in 1977 will be remedied in 1978.

2) Plant water potential was measured at dawn weekly and once a month throughout a day. These measurement schedules will be continued in 1978. The spring rains which soaked the soil also kept the plant water potential very low through June, but as the summer heat began to dry the soils, plant water stresses rose and exceeded 15 bars by mid-July in the control plots at both sites. Natural and irrigated showers of less than 6 mm appear to have little effect on plant water potential in July and August. Whereas one or

more 12 mm showers in these months can lower plant water potential considerably, but only for a short period of time. In 1978, plant water potential will be correlated to photosynthesis to determine at what stress during the growing season plants are capable of turning on photosynthesis.

3) By correlating leaf growth with plant water potential, some very interesting results are evident. With an unlimited water supply on a wet plot, growth of *Agropyron smithii* increased until mid-June and then decreased progressively throughout the remaining summer even though the soil was still saturated with water. The same growth response was observed in *Bouteloua gracilis* except growth started to decrease in late July. Water potential of *Agropyron smithii* exceeded 15 to 20 bars by mid-June on the 6 mm and control plots, but these plants were still capable of responding to additions of water over 12 mm until August. At this time, the plant growth responses of *Agropyron smithii* in the wet, 6 mm, and control treatments were not different. Growth data for *Bouteloua gracilis* on the 6 mm and control plots is not available due to infestation of grasshoppers, but this problem will be remedied this summer.

4) The number of culms increased in all plots and is especially evident in the wet plots in early August when growth had declined to the minimum of less than 10 mm per week.

5) Forage production will again be measured next summer at both sites using a capacitance meter and by clipping. Our preliminary conclusions suggest that *Bouteloua gracilis* can make better use of additional water than can *Agropyron smithii* even though, total production of *Agropyron smithii* is considerably greater than that of *Bouteloua gracilis*. The increase in forage yield on the 6 mm summer shower plots were small or nonexistant compared to the control plots. These findings seem to suggest that an additional 6 mm of

water added weekly will have little or no effect on forage production. Small additions of water as in the 6 mm plots, however, can extend the growing [illegible] slightly.

6) The roots of *Agropyron smithii* and *Bouteloua gracilis* were extracted and weighed from the 0-10 cm soil layer, 10-30 cm layer, and 30-50 cm layer. The results showed that more roots were found in the 0-10 cm layer. This finding has adaptive value for it indicates that these plants are able to absorb small amounts of rainfall in light showers. The data also suggests, however, that showers must be greater than 6 mm for the water to permeate this soil and to be absorbed by the plants in July and August when the soils are dry. Root biomass increased markedly during the growing season, but was not affected by the different water treatments. These results suggest that fe roots are necessary for supporting the larger aboveground biomass.

7) Of the seven mesic native grasses which were planted in all treatment at both sites, only four of them became established on the wet and spring wet plots. None became established on the control or 6 and 12 mm summer shower plots. Several weedy species invaded each site.

8) Seed production of *Bouteloua gracilis*, but not of *Agropyron smithii*, increased on the wet and spring wet plots. Seed production did not increase on the control, 6 mm, and 12 mm shower plots at either site.

9) The single shower experiment will be enlarged next summer because of the very interesting results that were obtained in 1977. These results showed that a plot saturated with water in July will increase standing crop considerably more than a plot saturated in August. The standing crop of a plot saturated in September was similar to the control plot which received no additional water. These results suggest that as the season progresses, growth of both grasses is limited more by day length than by water.

10) Species and numbers of grasshoppers were more abundant on the *Bouteloua gracilis* sites than on the *Agropyron smithii* site. Within both sites, grasshoppers were more numerous at the dry than wet plots, indicating a greater palatability of dry grasses.

11) Decomposition rates were higher on the wet and spring wet plots. More data will be collected in future years to obtain a better correlation between soil water, nitrogen fixation and decomposition.

12) Ergot, a fungus of seedhead which causes abortion in cattle, was the only fungus observed on *Agropyron smithii* but only in the wet plots. No detectable increase in leaf spot fungi was observed with increased water at either site. The two sites will be examined closely in future years for fungal and bacterial diseases.

ECOLOGICAL EFFECTS OF PRECIPITATION ENHANCEMENT ON EASTERN MONTANA RANGELAND

An Irrigation Study

Study Design

MONTANA DEPARTMENT OF NATURAL RESOURCES AND CONSERVATION
Helena, Montana
and
MONTANA STATE UNIVERSITY

June 1977

INTRODUCTION

An important aspect of the High Plains Experiment (HIPLEX) research projec is to determine the immediate and mid-term responses of native rangeland ecosystems to additional moisture. This information is essential for it will allow operators of precipitation enhancement programs to know the season, amount and frequency of additional moisture needed to maximize forage production of native range grasses. The following study is a controlled irrigation experiment designed to accomplish part of this objective.

Information will be gathered on the short (1-2 year) and mid-term (3-6 year) effects of precipitation enhancement programs on native ranges of eastern Montana. Two storm characteristics will be emphasized. 1) Seasonality -- the effects of spring, summer, and fall moisture on forage production. Other irrigation experiments have provided so much water that their relationship to weather modification is hard to determine (Lauenroth and Si 1973; Perry, 1976). 2) Frequency-quantity -- the relative value of one inch of additional precipitation per month when it comes in weekly quarter inch showers or fortnightly half inch showers. Little or no evidence is available on the effects of adding small amounts of water to native range in different ways (cf. Perry, 1976). Since production is well correlated with transpiration (Chang, 1968), occasional heavy showers should be more beneficial because water will penetrate deep enough into the soil to be used by plants rather than lost by simple evaporation.

The study is designed as a six-year project. During the first two years detailed measurements of plant growth will be made and related to the different water regimes imposed. The following four years will be used to measure production, composition, seedling establishment, and decomposition.

The study is proposed as a cooperative effort between Montana State University and Montana Department of Natural Resources and Conservation and its staff.

OBJECTIVES

To determine how range ecosystems would be affected by different patterns of increased rainfall, the following objectives will be pursued:

1) the effects of additional rainfall on phenology, forage production and quality and seed production of *Agropyron smithii* (western wheatgrass) and *Bouteloua gracilis* (blue grama),
2) the relationship between plant growth and plant and soil water potential,
3) the effect of additional rainfall on certain aspects of ecosystem structure and function such as root-shoot ratio, nitrogen distribution, and decomposition rates, and
4) the stability of grasslands with increased moisture.

MATERIALS AND METHOD

I. Site Locations.

The study will be conducted at two deep soil sites located on Fort Keogh National Range Experiment Station near Miles City, Montana; one site is dominated by *Agropyron smithii* (a cool season grass) and the other is dominated by *Bouteloua gracilis* (a warm season grass). Relatively pure stands, rather than more common mixed stands, will be chosen to facilitate the determination of these grasses individually. These grasses, along with Stipa comata (needleandthread) are the principal range grasses of the region.

II. Treatments.

A total of 12 plots (10 x 10 m) will be located within each site; 10 plots will be given five treatments replicated twice and two control plots will remain unirrigated. The control plots will receive only naturally occurring rainfall. To prevent lateral movement of water between plots, sprinkling of plots will not occur when winds are greater than 2-3 miles per hour and an 8 m strip will separate individual treatments. Subsampling within each treatment will allow statistical analysis.

Each 10 x 10 m plot will be irrigated with four "Rainjet" sprinklers distributed to provide uniform coverage. Water from the Yellowstone *(Agropyron smithii* site) and Tongue *(Bouteloua gracilis* site) Rivers will be applied. Large material in the river water will be removed with filters and centrifugal separators. Salts in the irrigated water will be measured periodically.

The following treatments are described.

A. Spring Wet Treatment. The plots will be watered to create a soil water condition like that found at a soil depth of 25 cm at Dickinson, North Dakota which is about 130% of that recorded at Miles City (Table 1). By adding 30% of natural showers a soil condition at Dickinson would not be created due to the "oasis effect." Therefore, Dickinson soil water status will be mimicked in Miles City creating plant responses similar to those observed under a Dickinson rainfall regime since plants respond principally to the availability of soil water (Daubenmire, 1943). Soil water will be held at field capacity until early July.

TABLE 1. Average precipitation at Miles City, Montana and Dickinson, North Dakota (USDA 1941).

Period	Annual	APR	MAY	JUN	JUL	AUG	SEP
Miles City	13.16	0.97	1.89	2.42	1.67	1.20	1.07
Dickinson	15.38	1.06	2.26	3.39	2.17	1.87	1.20
% Increase	120%	110%	120%	140%	130%	155%	110%

B. Frequent Light Showers. These plots will receive 6 mm of rain per week. Rain falling the previous week will be subtracted from the addition. This treatment is intended to model light rains created by a cloud-seeding program. Precipitation additions larger than light showers will be made in the evening or early morning (minimizing evaporation) to partially compensate for the high evaporation rates experienced by small plots ("oasis effect"). Most of the water added is still expected to evaporate without effecting plant growth and community dynamics.

C. Occasional Moderate Showers. These plots will receive 12 mm of rain fortnightly. Again, rain falling the previous two weeks will be subtracted from the addition. This treatment is intended to model intensive cloud-seeding when especially good conditions arise. Greater effects are expected from this treatment than from the light shower treatment, because more water should penetrate the deep soil layers to be used by plants and less lost through evaporation.

D. Wet Treatment. Soil water in these plots will be held at field capacity and soil water stress will not exceed two bars at a soil depth of

25 cm. Even though such conditions cannot be achieved through weather modification, they will show the maximal growth response that could be achieved if water is not limiting.

E. Fall Wet Treatment. The soil profile will be saturated with water in September in these plots to model intensive seeding of early fall storms. Such cloud-seeding should be beneficial for both fall and spring growth (cf. Rogler and Haas, 1947), but it may also increase weedy *Bromus* species. The information derived from this treatment may help operators of cloud seeding programs to know if more or less effort is beneficial in the fall to relieve a possible drought the following summer.

III. Measurement of Responses to Treatment.

Each plot will be divided into ten strips (9 x 1 m) for replicated measurements of physical and biological responses to increased water. Within each plot one strip (9 x 1 m) will be fertilized with 100 kg/ha of nitrogen to determine the extent nitrogen may limit the system. Figure 1 illustrates the arrangement of plots within each site and Figure 2 the ten strips within each plot.

The following parameters will be measured:

A. Soil Water. Irrigation of plots is expected to increase soil water. The magnitude of this effect will be measured at soil depths of 10, 25, and 75 cm weekly with plaster "Bouycous blocks" buried at four locations in each plot. For comparison, some plots will be instrumented with thermocouple psychrometers.

B. Nitrogen Availability. Irrigation may affect soil nitrogen availability either through microbe release-plant uptake dynamics or through leaching. Total nitrogen, ammonium nitrogen, and nitrate nitrogen will be measured in the 0-30, 30-60, and 60-90 cm soil layers early in the spring during the green-up stage probably when nitrogen is most available and after maximum standing crop when nitrogen should be least available. Each sample will consist of five pooled cores (one sample x 3 depths x 2 reps per plot x 2 plots per treatment x 6 treatments x 2 sites x 2 measures per year = 432 samples/year).

C. Plant Water Potential. By adding soil water, plant water potentials should be reduced. 1) To measure this, plant water potential will be measured once weekly before watering in one replication (= six plots per site). Between six and seven a.m.,one stem will be measured, than a second stem, etc. until five to ten stems have been read in each treatment. 2) To relate the daily cycle of water stress to the "dawn" measurements, water stress will be measured at 5 a.m., 8 a.m., 11 a.m., 2 p.m., 5 p.m., and 8 p.m., on clear days every two weeks. In these measurements five stems will be read from the control plot, five from the wet plot, etc., until all treatments have been studied. Weekly measurements will allow water potential to be contrasted between treatments, while the "water potential days" will be used to determine the daily trends in water potential within specific plots. Plant water potential will be correlated to soil water potential in each plot.

D. Plant Phenology. If soil water is increased by sprinkling, plants might stay green longer and flower longer. To determine whether phenology of *Bouteloua gracilis* and *Agropyron smithii* are affected, the percentage of plant material which is green and in the flowering state (boot, green head, dry head, seed shed) will be recorded on five 0.6 x 2.4 m plots weekly. A general record of phenology of any other plant which is flowering in these plots will also be noted. Phenology plots will be located in the unfertilized capacitance meter strips.

E. Plant Growth. If soil water is increased and plant water stresses are reduced by watering better growth is expected. Detailed measurements of leaf initiation, leaf elongation, and tiller initiation of *Agropyron smithii* and *Bouteloua gracilis* will be recorded in replication I at the respective sites.

To contrast the seasonal pattern of grass growth between treatments, leaf production of *Agropyron smithii* and *Bouteloua gracilis* will be made by marking 25 stems of each species with red thread at the base and recording the status of leaves (birth, live, dead tip, dead, and lost) by leaf number weekly (cf. Golubov, 1971). Leaf length of *Agropyron smithii* will also be measured. Tillers in a small plot (containing 25 to 50 tillers) will be marked and counted into new, live and dead classes weekly. This would be very difficult in *Bouteloua gracilis*, so changes in basal cover will be measured instead.

F. Forage Production. Less detailed measurements of growth will be made with a capacitance meter to study more treatments, to replicate our experiment, and to determine the response of grasses to water if nitrogen is not limiting. In each plot 22 unfertilized and 22 fertilized quadrats (1 x 30 x 60 cm) will be remeasured weekly to compare relative growth rates between treatments. Five quadrats from each plot will be clipped monthly to provide an absolute measurement of production and will be used to calibrate the capacitance meter.

G. Forage Quality. Protein content of plant material may decrease if steminess increases because of additional water. In contrast, simultaneous increase in total aboveground nitrogen may occur if adding water results in increased decomposition rates coupled with increased plant uptake. To determine these effects the nitrogen content of grasses clipped in June, July and August will be analyzed (three samples per plot x 6 treatments x 2 reps x 2 sites x 3 dates = 216 samples/year).

H. Seed Production. Seed production might increase by sprinkling. To estimate this, the number of flowering clums will be counted for each plot until a mean with a standard deviation of 20% of the mean can be determined. If time permits, this procedure will be repeated on the fertilized strips.

I. Root-shoot Ratios. Root-shoot ratios generally decrease with more available water. This phenomenon will be demonstrated by taking root cores in August or September of each year. Five cores per plot will be pooled by horizon (0-15, 15-30, 30-45, 45-60, 60-75, and 75-90 cm) for one sample (one sample x 6 depths x 3 reps per plot x 6 treatments x 2 reps x 2 sites x 1 date = 432 samples). A set of root cores will be taken before treatments are initiated to show the similarity between plots.

J. Range Composition. Vegetation composition is expected to change under a regime of enhanced precipitation since sites with different moisture regimes usually have different community composition. The succession may involve increasing density of existing vegetation of eastern Montana to the climax vegetation of western North Dakota or it may involve degradation of existing vegetation with replacement by weeds and then succession to the more mesic climax.

To record changes in composition that will occur in the six-year period of our experiment, the following will be recorded: (1) species present in each plot annually, (2) the average height of the grass leaf layer at maturity and the average height of the culm layer at maturity, and (3) the basal cover by species. The basal cover will be measured at a minimum of three hundred points per plot and at least once annually (mid-July).

Grasses of eastern ranges may not appear in our plots even though they could establish under the moisture regimes provided (and would under a precipitation enhancement program in time) because seed sources are so distant. To test the ability of mesic species to establish themselves (by "natural" or human dispersal) seeds of *Agropuron trachycaulum, Stipa viridula, Andropogon scoparium, Bromus inermis, Panicum virgatum, Andropogon gerardii*, and *Sorghastrum nutans* will be planted into quadrats. One hundred viable seeds will be seeded into three 3 x 6 dm quadrats in each treatment plot (= 6 reps). Germination will be noted in June of 1977 and survival will be noted each fall.

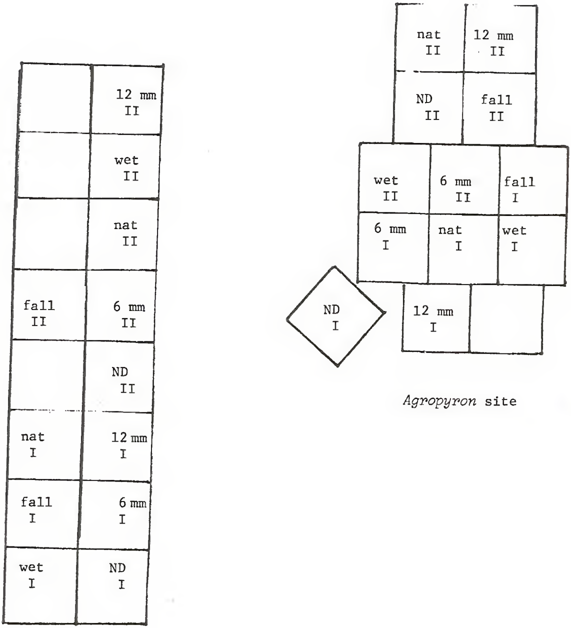
K. Plant Pathogens. Fungal and bacterial diseases are usually encouraged by increased moisture so they might be expected to be most prevalent on our wettest plots. In August a minimum of 200 stems on each plot will be examined to determine the frequency of leaf spots. Diseased plants will be collected and preserved for more detailed laboratory examination at MSU.

L. Decomposition. Under constant temperature and adequate oxygen, decomposition rates are expected to increase with an increase in soil moisture. To verify higher decomposition rates on moist plots (making nutrient more available there), small stakes will be driven into the ground and their weight loss observed. This estimate of decomposition rates will be minimal because fungal and bacterial bodies will be incorporated into the wood. Observations will be made in the spring (April) and in the fall (October) because all plots will be treated similarly during the winter months (October-April) and differently during the summer months (April-October). (Five stakes per observation x 6 treatments x 2 reps x 2 sites x 2 collections per year x 6 years = 1440 stakes, 60 per plot.)

M. Insect Utilization. Insect damage might be greater on moist plots either if insect populations thrive there or if greener vegetation is more palatable and attracts insects to the moist plots. In August a minimum of 200 plants will be examined on each plot to determine insect damage on each plant. Usage will be recorded separately for the first leaf, the second leaf, the third leaf, etc.

Soil arthropod numbers may be maintained at higher levels on the wet plots than on dry plots.

N. Changes in climatic conditions will be measured either continuously or weekly at each site. Precipitation by storm, amount and frequency will be measured by a continuously recording Belfort weighing rain gage with its orifice about 1 m above the ground. Wedge rain gages will be scattered randomly on each site with their orifices about 8 cm above ground level. By installing these gages at 8 cm the effects of wind will be reduced allowing a more accurate measurement of precipitation amounts and spatial distribution of daily rainfall on each study area. Solar radiation will be measured continuously with a recording solarimeter. Air temperature and relative humidity will be measured with a recording hygrothermograph. Wind speed will be measured with a totalizing anemometer. These measurements will be related to evapo-transpiration, and soil and water potential as necessary.



Bouteloua Site

Agropyron site

Figure 1. Arrangement of plots within the two experimental sites

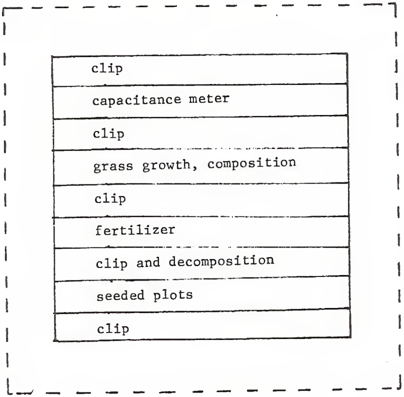


Figure 2. Strips within a 70 x 70 ft treatment plot

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WEATHER MODIFICATION EFFECTS ON CARBON CYCLING AND COMMUNITY DYNAMICS OF CONSUMERS AND DECOMPOSERS IN GREAT PLAINS RANGELANDS

1977 Annual Report

Submitted to:

HIPLEX Project
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Introduction

There were two primary emphases during 1977 work on weather modification effects on rangeland carbon cycling and grazing food chain dynamics. The first was to locate and obtain access to rangeland where experiments using water level treatments (mimicking rainfall increases) and cattle grazing could be done concurrently. Secondly, I studied the aboveground arthropod community and its dynamics in grasslands dominated by physiologically and structurally different native grasses. The purpose in this latter regard was to develop techniques appropriate for future intensive work; determine the general range of diversity, abundance, and biomass to be expected under control conditions; and to compare findings to those made by other HIPLEX researchers on other ecosystem components.

Successful weather modification of convective thunderstorms in the northern Great Plains is likely to increase rangeland plant productivit Other ecosystem effects mediated through the driving variable of soil moisture may be anticipated. These will probably be of lower order importance. Yet Perry (1976) noted that eventual long term and even short term ecological changes in features other than plant biomass may be of significance. He felt important changes in rates of nitrogen cycling would occur with the onset of weather modification.

Increases in total ecosystem respiration, alteration of fixed carbon allocation pathways to greater underground storage with the onset of rainfall increases, or increased arthropod consumption could substantially affect the yield of forage. Since weather modification is being pursued largely for its anticipated economic benefits and rangeland forage is a useful economic commodity, the consideration of changes in fixed carbon movement in the ecosystem is of interest.

While not all species in an ecosystem can be studied efficiently it is possible to describe major functional changes by selecting dominant groups. Numerically, arthropods are often dominant animals in grassland ecosystems (Van Hook 1971). Arthropods and ungulates account for the greatest energy flow in the grazing food web of rangeland ecosystems; it is likely they contribute a great deal to mineral dynamics, as well. Experiments planned by this author will test several hypotheses concerning arthropod-cattle, herbivore-sap feeder, and herbivore-carnivore relationships as altered by increased soil moisture.

SITE LOCATION

A great deal of time during June, July, and August, 1977 was spent searching for a site to conduct experiments on weather modification effects on rangeland environments. Possible 12 ha sites had to be very close to either the Tongue or Yellowstone Rivers for the legally available water, be of mixed species range and preferably unplowed, be only a short distance above water, be accessible by vehicle, be on fairly level terrain and of generally uniform soil composition, be available to cattle, and be available for two years of experiments.

Most areas within daily driving distance of Miles City and meeting the first several criteria are no longer rangeland. They are now irrigated cropland. In the company of several HIPLEX personnel the search for sites was conducted by vehicle, review of recent aerial photos, and reconnaisance from low-flying airplanes. Several possible sites emerged from the search.

A good quality area within 10 km driving distance of Miles City on the north bank of the Yellowstone River was requested from a private landowner. After some consideration the landowner refused permission. Another north bank of Yellowstone River site was located 60 km from Miles City.

The landowner gave tentative permission for its use,but the long driving time, nearly monospecific range composition (blue grama grass), and history of cultivation or very intensive disturbance prompted a continuation of the search.

Permission to seek a site on the Livestock and Range Research Station of the Agricultural Research Service (ARS), U.S. Department of Agriculture (USDA) was granted in early August. On 11 August I drove to several sites along the Tongue River with Mr. Wayne Milmine of the Station's staff. He and Mr. Ray Woodward, Station Director, later gave their tentative approval to two year use of rangeland on the Station's South Tongue River Bend pasture. A written request for permission to conduct experiments there was granted within the month by officials in the ARS, USDA. A copy of the agreement, with constraints of use, is in the HIPLEX office in Miles City.

The site available for research is located on the west bank of the Tongue River in" NE ¼, SW ¼, Sec. 25, T. 7 N., R. 47 E. This corresponds to an earth polar coordinates location of: 46° 19' 45" N. latitude and 105° 47' 30" W. longitude. It is located on the Paddy Fay Creek quadrangle map of the U.S. Geological Survey.

Mr. Michael A. Nichols of the Soil Conservation Service conducted a soil analysis of the site on 12 August. His report includes the following information pertinent to this study. The soil is a Chanta loam classified as an Aridic Haploboroll which is fine-loamy and mixed. The soil developed on Tongue River alluvium over a sandstone formation and is on a bench with simple, concave relief. The soil report projects permeability to be moderately slow in the surface layers and rapid below that. A layer of stones is located at about 50 cm depth. More specific information on the soil characteristics may be found in Table 1. A major feature to note is the caliche layer in the B_{3ca} and C_{1ca} horizons at 50-80 cm.

Major site physical features including experimental plot locations are referenced in Figure 1. Water will have to be pumped 27 m up from the river and then over varying lateral distances. Vegetation composition, soil, and relief were sufficiently uniform to allow a completely randomized design in plot location. The plots were staked in late August. They are 71 m square (one-half ha) with 15 m bufferstrips. Treatments are to be ungrazed (U)-cattle grazed (G) and control (C)-"western North Dakota" (WND)-"central North Dakota" (CND). Experimental design has been discussed in other reports by this author and included as Appendix 1 to this report.

The salient points about the experimental treatments is that cattle grazing will be controlled to a moderate level of use during the growing season, and water treatments will be made to hold soil moisture stress between -1 and -5 bars until early July on the "western North Dakota" treatment and late July on the "central North Dakota" treatment. Level of cattle use will be set in consultation with Livestock and Range Research Station managers,and soil water status will be measured by the "Bouyoucos" plaster block method.

Vegetation on the site is predominantly big sagebrush (*Artemisia tridentata*), silver sagebrush (*A. cana*), needle and thread grass (*Stipa comata*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), dryland sedge (*Carex filifolia*), and cheat grass (*Bromus tectorum*). These plants are common rangeland dominants in the northern Great Plains. Other grasses and forbs noted as present were: green needlegrass (*Stipa viridula*), sideoats grama (*Bouteloua curtipendula*),

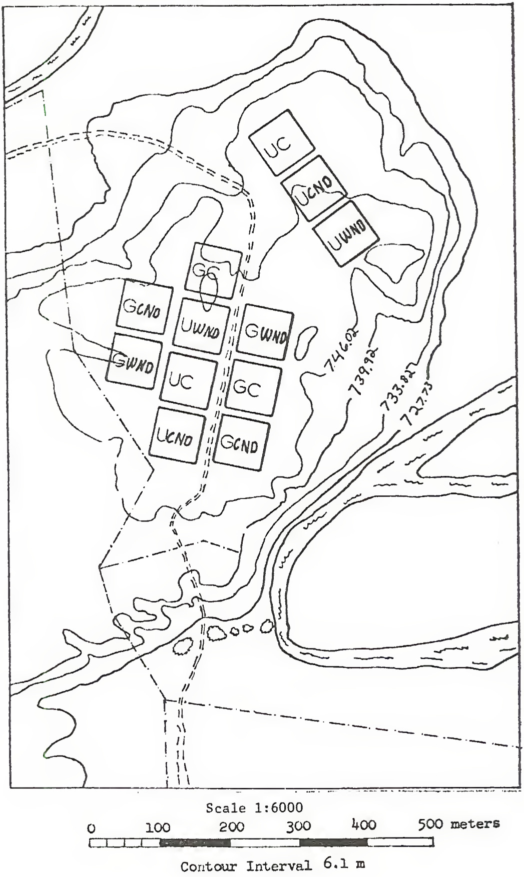
Table 1. Soil analysis of the HIPLEX research area on the South Tongue River Bend pasture of the Livestock and Range Research Station, Miles City, Montana. Analysis by the Soil Conservation Service in August, 1977 (Michael Nichols, personal communication).

Horizon	Depth (cm)	Crushed Colors		Texture	Structure	Consistence			Reaction (pH/e)¢	Boundary	Roots	Salts	Coarse Fragments
		Dry	Moist			Dry	Moist	Wet					
A_1	0-7.6	10YR512	10YR312	loam	weak, fine granular	sl. hard	very friable	sl. sticky & plastic	8.2/e0	abrupt smooth	many, fine & very fine	---	---
B_{21}	7.6-30.5	10YR413	10YR313	heavy loam	#	"	"	" sticky & plastic	" / "	clear smooth	"	---	---
B_{22}	30.5-50.8	10YR513	10YR313	loam	mod., coarse prismatic to str., med., & coarse subangular block	"	"	"	" / "	grad. wavy	" "	--- ---	--- ---
B_{3ca}	50.8-61.0	10YR613	10YR413	loam	str., coarse prismatic to str., med., ang. block	"	"	"	9.2/ev	"	many very fine & com. fine	evm + 2sm 2ss	5%
C_{1ca}	61.0-81.3	10YR713	10YR513	loam	massive	"	"	"	" / "	abrupt smooth	com, very fine	"	"
IIC_2	81.3+	salt & pepper		med. & fine sand	loose	loose	loose	nonst. & nonplastic	9.0/es	---	---	---	15%

¢-efferv[illegible]scence: e0-none, es-slight, e-moderate, and ev-viol[illegible]

#-weak very coarse pris at [illegible]

Figure 1. Map of HIPLEX research area on the South Tongue River Bend pasture of the Livestock and Range Research Station, ARS, USDA. Area: SW ¼ and S ½, NW ¼, Sec. 25, T. 7 N., R. 47 E.



ç-efferv scence: e0-none, es-slight, e-moderate, and ev-violent.
#-weak very coarse prismatic parting to str. very coarse platy parting to mod. med. & coarse subangu-
lar blocky + violently effervescent: mod. soft lime masses & med. lime seams.

prairie June grass (Koeleria cristata), Indian rice grass (Oryzopsis hymenoides), prickly pear cactus (Opuntia polyacantha), and goatsbeard (Tragopogon dubius). A more complete species list will be made in the next field season.

Grass litter was present over much of the site, and bare ground was relatively minor in coverage. Seasonal cattle use was noted to be primarily of dryland sedge and few other plants. My impression of present cattle grazing pressure is that it has been light to moderate on the area. Reinforcing this impression were the presence of sage grouse (Centrocercus urophasianus), sharp-tailed grouse (Pedioecetes phasianellus), desert cottontails (Sylvilagus auduboni), and the particularly abundant microtine rodents, either sagebrush voles (Lagurus curtatus) or prairie vole (Microtus ochrogaster).

The last-mentioned mammals have been documented to be abundant in rangeland only when a litter layer is present and vegetation height is relatively great (Birney et al. 1976). Heavy cattle grazing would diminish litter cover and lower the height of standing grass. The late season grasshopper community seemed to be no different than those on surrounding rangeland, that is a few adults lingering from populations past their peak and a few nymphs from species that will overwinter above ground.

1977 ARTHROPOD STUDIES

Materials and Methods

Sweep net samples at the wheatgrass (Agropyron smithii) and grama (Bouteloua gracilis) sites being intensively studied by HIPLEX researchers were taken biweekly between 0900 and 1300 hours, wind and rain permitting. Each sample set consisted of ten five-minute continuous sweeps. The net was swung vertically and at the lowest point in the arc nearly touched the ground. Because of the short vegetation the entire plant canopy could be sampled in each arc. The path for each sweep was described by randomly chosen coordinates. Coordinates were defined by fence posts at each location in the several ha of land surrounding each set of experimental plots being used in plant ecology experiments.

At the end of five minutes the sweep sample was placed in a paper sack and the sack placed in a cooler packed with ice. This served to reduce intra-sack predation and metabolism. Samples were frozen within three hours of collection. They were later separated by hand under a dissecting microscope. An exception was the set of mid-July samples at both locations which were stored in 70% ethanol following unsuccessful Berlese funnel extraction. Many seeds sifted through the extractor mechanism necessitating hand sorting, too. Biomass from alcohol preserved samples is lower than in frozen samples because of loss of soluble lipids. Thus the mid-July samples are somewhat lower by comparison to the others in weight.

The number of grasshoppers by size class and species was recorded. Adult males and females were tabulated separately. All members of each species were collectively weighed after a 48 hour period of oven drying at 65° C.

The number of sweeps per sample was counted and mean and standard error determined for four sample sets during the season (two at each location). The means (std. errors) of ten sweeps each are: 640.6 (2.2), 640.4 (2.0), 642.6 (3.3), and 638.8 (3.5). They are statistically similar by the Student's t-test. Area of ground sampled per sweep sample can be calculated roughly by:

(mean no. of sweeps) X (mean sweep distance) X (net diameter)

where mean number of sweeps = 640, mean sweep distance = 1.4 m, and net diameter = 0.32 m. This is 287 m^2 which can be used to divide into arthropod numbers and biomass to express them on a square meter basis. Menhinick (1967) used a variation of this method for quantitative sampling in old field studies of arthropod numbers and biomass.

Methodological problems of arthropod sweep sampling are the reduced efficiency of sampling very small arthropods because the air blast preceding the net, escape through the net, and crushing in the debris. In addition, the relatively low efficiency of capture of ground dwelling forms is important to note. For that reason grasshopper nymphs may be undersampled. This effect may be partially compensated by the escape of flying adults disturbed in advance of the sweep. Variance is, though, much lower in these samples than those taken by most spot collections such as in drop nets.

Aboveground arthropod samples for types, numbers, and biomass on the twelve plots of the primary study site for 1978 and 1979 will be taken by three techniques. Fifteen or twenty drop net (0.5 m^2) samples per plot per week will be collected by vacuuming. These samples will be frozen and sorted by hand. Five sweep net samples of 50 sweeps per plot per week will give supplemental information on grasshopper community structure. Fifteen pit traps of open 12 ounce beverage cans will be placed regularly at the ground surface on each plot and collected weekly. This technique will sample the otherwise poorly collected ground dwelling arthropods (mostly beetles) and the shrew community.

Soil arthropods were sampled from root cores taken from 0-10 cm and 10-30 cm depths, respectively in the soil profiles of the control, "wet", and "western North Dakota" treatments of the wheatgrass (24 June, 1977) and grama (7 July, 1977) sites. Mr. John Newbauer, III collected these samples. The cores were pooled as five core sets into one sample. Three replicates of each sample were taken. The cores were placed in paper sacks in the field and extraction of organisms was made according to the steep gradient method of Merchant and Crossley (1970). Refrigerator space allowed extraction of only ten samples at one time. The remaining samples were stored within their sacks in another refrigerator.

Core samples were weighed, mixed by hand, and 20% (10%) by wet weight of each 0-10 cm (10-30 cm) sample was placed in an extractor funnel lined with fine window screen material. The funnel was placed at the low end of a 12 ounce beverage can and a 7 watt light bulb placed at the other. Aluminum foil was sealed over the top of the can. Arthropods moved away from the heat of the bulb and dropped into a vial of preservative (70% ethanol). Sorting took place under a dissecting microscope when all samples had been extracted.

Extraction efficiency and uniformity were hampered by soil dropping into the collection vial, loss of natural paths for movement of the arthropods, refrigerator storage of some samples, sticking of some arthropods to the funnel walls, and the different proportions of soil water at different depths altering soil weights. Future soil arthropod samples will be taken from single, non-mixed cores and extracted directly into gridded Petri dishes for counting (Tim Seastedt, personal communication).

The variability in natural rainfall was tested by placing 25 wedge gauges in a Cartesian grid of 71 m X 71 m outside dimensions. This grid was located at the Miles City airport and was used to sample three late August, 1977 rains. Each gauge was staked 5 cm from the ground at its bottom, was leveled with a spirit level, and received several ml of brake fluid to reduce water evaporation. The wedge gauges were read at 24 hour intervals for three successive days.

Results

Table 2 lists identified grasshopper species captured in selective sweep samples and by hand with their common habitat associations. A reference collection of these has been developed to ease future identification problems. The community likely to be sampled on any one site will be of just ten to fifteen species. The species in Table 2 are from four subfamilies of Acrididae and one member of the family Tettigoniidae. Those species captured in grama and wheatgrass systematic samples are identified in Table 2 by an asterisk. Ms. Dayle K. Haglund made the identifications.

The entire set of grasshopper data has been analyzed comparing the two communities and values at different dates within each community. The results are not yet compared to the soil moisture, weather, nor plant biomass compiled and analyzed by other HIPLEX researchers. These comparisons will be made during a group meeting in January or February, 1978. Predatory and sap-feeding arthropods have not yet been sorted due to complications from severe illnesses in my family during October-December, 1977. These samples will be readied for presentation at the 1978 winter meeting.

Most of the grasshopper species present in the samples of either the wheatgrass or grama sites were present in the other. Yet the communities as measured quantitatively never had more than 46% similarity according to the coefficient of community similarity (C.S. %):

$$\text{C.S. \%} = \frac{2\ (a)}{w + g} \times 100$$

where a= least number of individuals in each species common to both sites and w and g are the total number of grasshoppers on wheatgrass and grama samples, respectively. The coefficient can range from 0 % (no similar species) to 100 % (identity). The mid-summer course of similarity (Fig. 2) shows increasing similarity as the populations declined in density from late June to mid-August with a small drop in similarity thereafter.

Table 2. Thirty three grasshopper species from rangeland environments near Miles City, Montana collected during summer, 1977.

Family:Acrididae	Favored Habitat
Subfamily:Romaleinae	
Brachystola magna	Dry, grassy areas; short grassy areas
Subfamily: Acridinae	
Ageneotettix deorum *	Dry, short grasses; grassland where vegetation is scanty or soil exposed and sandy; sandy soils with weeds
Aulocara ellioti	Dry, short grasses; short grass areas
Eritettix simplex *	Grassy areas, old fields
Mermeria maculipennis *	Lush, high grass; range and cultivated areas; tall grass
Opeia obscura *	Dry, low grasses
Paropomala wyomingensis *	Grass in moist places
Phoetaliotes nebrascensis *	Grasslands and prairies
Subfamily: Oedipodinae	
Arphia pseudonietana *	Usually among dry, scanty, low grasses
Chortophaga viridifasciata	Low weeds and grasses; marsh grasses
Circotettix rabula	Bare spots in open; dry, steep slopes of hills; steep, rocky, and eroded areas
Dissosteira carolina	Waste areas of poor soil; roadsides and waste fields; in towns, along roads and in cultivated areas
Encoptolophus sordidus	Dry, short grasses
Hadrotettix trifasciatus	Dry, short grasses; rocky or sandy areas, along roads, or on open grassy areas

(cont.)

Table 2 cont.

Hippiscus rugosus	Grasses, often open and sylvan; grassy areas, open woods
Metator pardalinus	Grasses and sedges; dry, short grasses
Pardolophora haldemanii	Dry, short grasses; dry, grassy areas where vegetation is heavy
Spharagemon collare	Mixed grass and herbaceous areas; dry, short grasses
S. equale	Bare soil of arid plains and along roads; dry, short grasses
Trachyrachis kiowa *	Dry, short grasses; grassy areas
Trimerotropis gracilis	Bare soil in sagebrush areas; scanty grasses in brush; sandy alkaline spots
Subfamily: Cyrtacanthacrinae	
Aeoloplus turnbulli	Dry herbage, often Chenopodium spp.
Dactylotum pictum	Low vegetation
Hypochlora alba *	White sage; hoary sage; common in sagebrush
Melanoplus bivittatus *	Open weeds and cultivation; lush vegetation about edges of fields and marshes
M. borealis	Lush grasses; marsh grasses, especially in dry seasons
M. confusus	Old fields, grass in open woods, sandy, gravelly soil; short grass, usually in open
M. differentialis	Yards, gardens and cultivated areas
M. femurrubrum *	Weedy and cultivated areas
M. packardii	Rank grasses and cultivation
M. sanguinipes *	Ubiquitous

(cont.)

Table 2 cont.

Schistocerca emarginata	High herbage near water
Family: Tettigoniidae	
Subfamily: Conocephalinae	
Conocephalus strictus *	Grasslands

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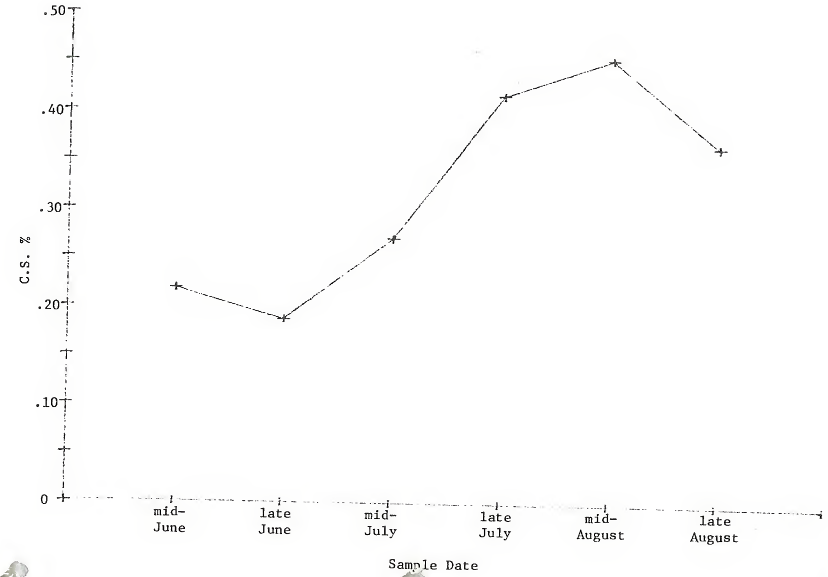
* collected at the grama or wheatgrass intensive sites

Habitat authority by Hebard (1928), Helfer (1971), Hebard (1936), and Dayle K. Haglund for Melanoplus differentialis.

Figure 2. Coefficient of community similarity between grama grass and wheatgrass HIPLEX intensive sites in summer, 1977.



The course of population change for the seven most abundant species at both sites are found in Figures 3 and 4. The changes for the entire community at each site are found in Figure 5. Pairwise comparison of date of maximum numbers and maximum biomass for species common to both types was made. Although the differences are not significant the wheatgrass type has a projected average peak for both grasshopper numbers and biomass in the second week of July. The grama type grasshopper community exhibits average peak numbers and biomass in the third week of June instead.

Season long data from the two grasshopper communities are summarized in Tables 3 and 4. Analysis of variance techniques were used to test for differences between and among the types by sampling period. Biomass of grasshoppers was found not to be normally distributed (calculated F-value less than 1.0) so a two-tailed rank sum test was used to make those comparisons. The two types had highly significant ($p<0.01$) differences in the number of grasshopper species present on the late June, mid-July, and late July sampling dates. The grama site exhibited a much greater ($p<0.01$) number of individuals on the mid-June and late June dates and a significantly ($p<0.05$) greater number of individuals on the mid-July date. Biomass was much greater ($p<0.01$) in the grama type samples than the wheatgrass type only for the mid- and late June samples.

Productivity of grasshoppers was far greater in the wheatgrass type. The turnover rates (productivity/biomass) were 4.66 and 2.41 for the wheatgrass and grama types, respectively. The method used was that of Hamilton (1969) which based on the life table method of Hynes and Coleman (1968). The basic algorithm for calculation of production by this method is:

P = Σ(no. of individuals lost from one size class to the next) X
(mean weight of the two size classes)

Figure 3. Numbers of individuals per sweep sample, mean, of each of the seven most abundant species of grasshoppers at the grama grass HIPLEX intensive site in summer, 1977.

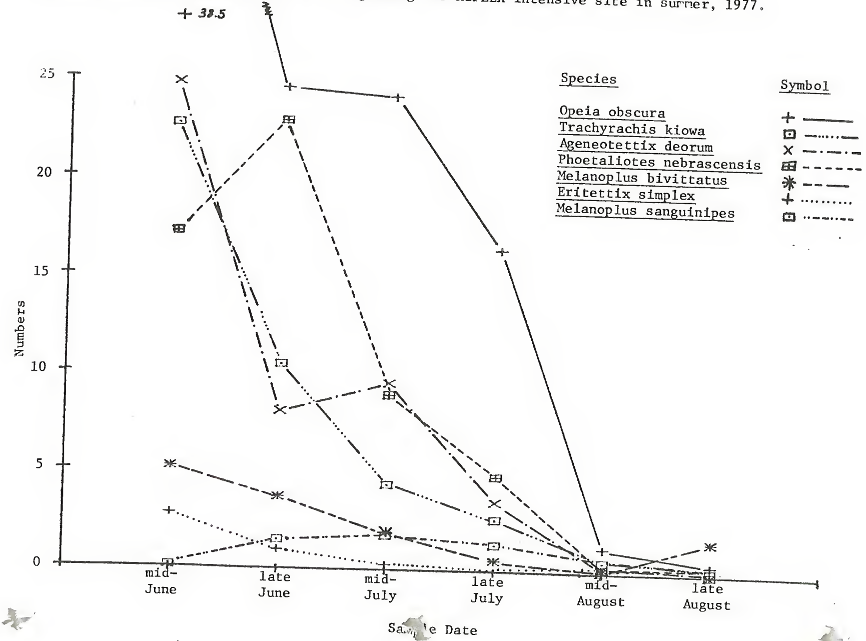


Figure 4. Numbers of individuals per sweep sample, mean, of each of the seven most abundant species of grasshoppers at the wheatgrass HIPLEX intensive site in summer, 1977.

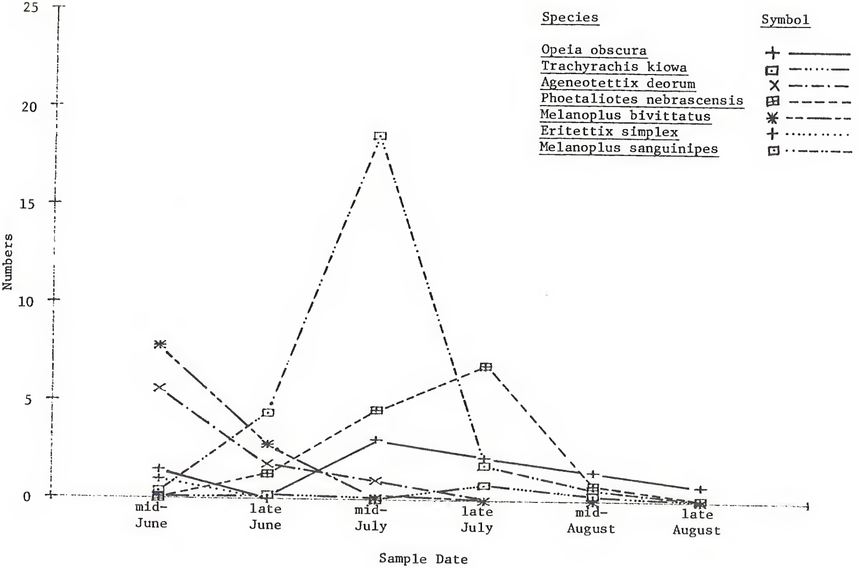


Figure 5a. Number of grasshopper species per sweep sample, mean and standard error, at HIPLEX intensive sites in summer, 1977.

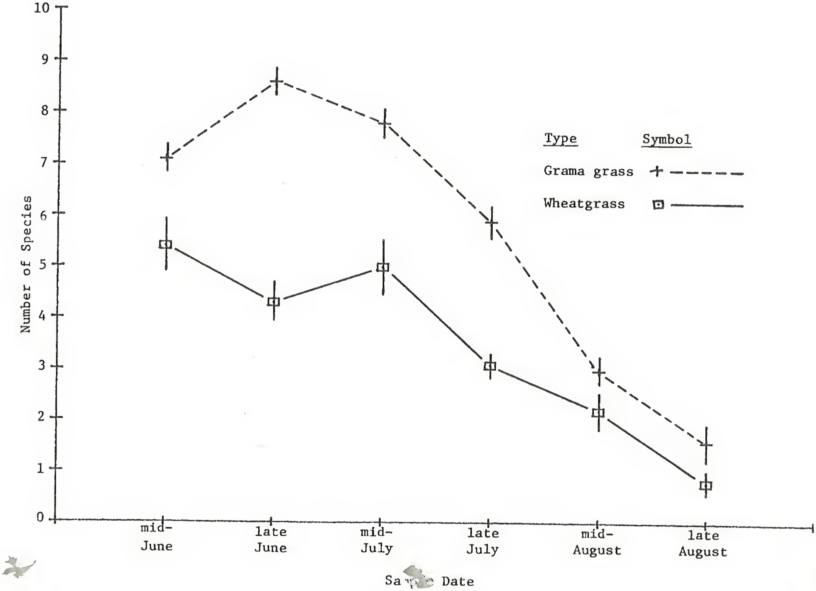


Figure 5b. Numbers of grasshoppers per sweep sample, mean and standard error, at HIPLEX intensive sites in summer, 1977.

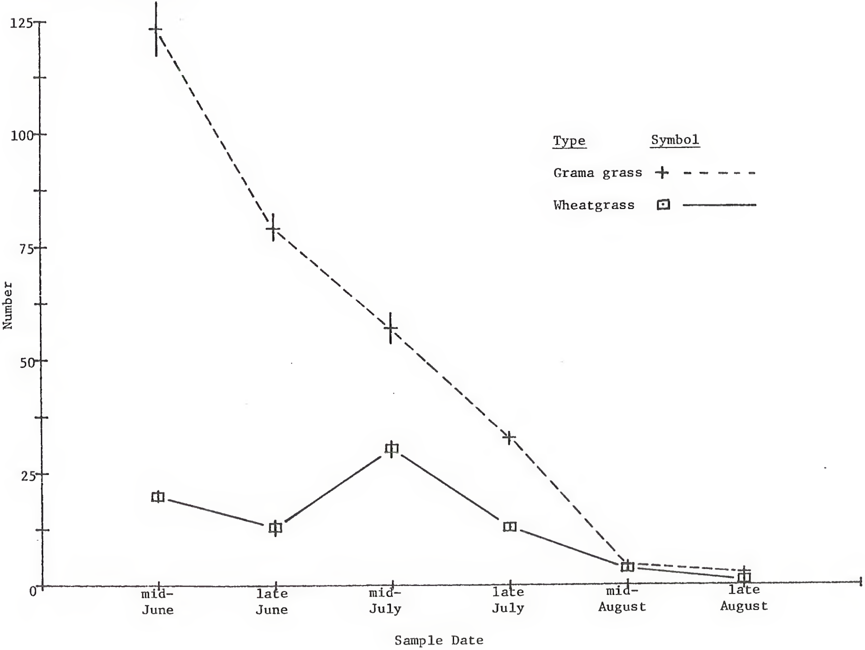


Figure 5c. Biomass of grasshoppers per sweep sample, mean and standard error, at HIPLEX intensive sites in summer, 1977.

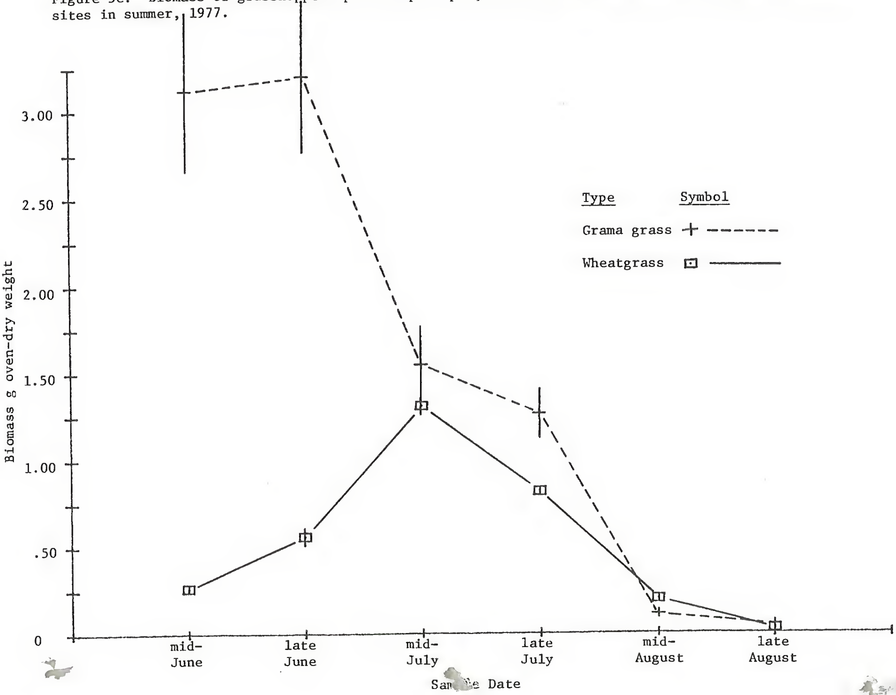


Table 3. Grasshopper community data for grama grass intensive site during summer, 1977. Values recorded per five minute sweep sample. N= 10 in all cases.

Date	Number of Species			Total Individuals			Total Biomass *		
	Mean	Std. Er.	Range	Mean	Std. Er.	Range	Mean	Std. Er.	Range
16/6	7.1	.28	6-8	123.1	13.07	67-207	3.12	.46	1.44-6.52
29/6	8.6	.31	7-10	79.0	5.21	52-97	3.20	.45	1.45-6.10
12/7	7.8	.29	6-9	56.8	7.92	28-100	1.54	.22	.78-2.70
28/7	5.9	.32	4-7	32.6	3.07	22-48	1.28	.17	.85-2.16
17/8	3.0	.33	2-5	4.3	.58	2-7	.11	.02	.05-.22
29/8	1.6	.43	0-4	2.7	.73	0-6	.05	.02	0-.15

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* biomass in g oven-dry weight

—— connects statistically equal means

Table 4. Grasshopper community data for wheatgrass intensive site during summer, 1977. Values recorded per five minute sweep sample. N = 10 in all cases.

Date	Number of Species			Total Individuals			Total Biomass *		
	Mean	Std. Er.	Range	Mean	Std. Er.	Range	Mean	Std. Er.	Range
15/6	5.4	.52	2-8	19.8	2.83	2-34	.26	.04	.02-.44
1/7	4.3	.39	2-6	12.9	2.92	4-24	.56	.11	.12-1.25
12/7	5.0	.58	3-8	30.3	4.00	15-59	1.31	.13	.73-2.02
29/7	3.1	.28	1-4	12.8	1.99	3-22	.82	.13	.23-1.41
17/8	2.2	.36	0-4	3.6	.62	0-6	.20	.05	0-.65
30/8	.8	.25	0-2	1.1	.41	0-4	.02	.01	0-.09

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* biomass in oven-dry weight

——— connects statistically equal means

As noted in both those above-mentioned papers an important assumption for accuracy is that all species be capable of growing to the same maximum size. This was true except for Opeia obscura. The males of that species did not grow to the 20-23 mm maximum length used in the table but as adults attained only 12-15 mm. Wheatgrass and grama type grasshopper turnover rates with O. obscura excluded are 4.78 and 2.50, respectively. In the wheatgrass type O. obscura male turnover rate was 1.28 and for females 1.33; in the grama type O. obscura males had a turnover rate of 1.02 and females had a turnover rate of 0.22.

Soil arthropod abundance (Table 5) was less in the deeper (10-30 cm) samples than in the 0-10 cm samples, but not significantly so. No tests for significance were made because of the unreliability of the extractions. As discussed above several problems in extraction and the relatively late date of extraction from the soil probably combined to cause few arthropods to be found in the collections. The former effect meant that few entered the preservative; the collection of cores probably took place after most of the organisms once alive in the season had died or entered diapause. Correlation of the data in Table 5 with "real" biological phenomena is likely to be spurious at best.

The mean (std. error) of the three rains as measured in the 5 X 5 grids at the Miles City airport in late August are: 0.37" (0.002), 0.37" (0.002), and 0.01" (0.001). Variation is extremely low relative to the mean. Thus natural rainfall is nearly entirely homogeneous on plots the size of the 71 X 71 m squares to be used in experiments. Irrigation by sprinkling is very unlikely to achieve that degree of uniformity. A shifting of sprinkler head location from one sprinkling period to the next should keep the season long distribution of water acceptably uniform.

Table 5. Soil arthropod counts, mean and (standard error), from three sets of soil cores taken on HIPLEX intensive sites in summer, 1977. See text for actual dates.

Depth	Wheatgrass			Grama grass		
	Control	"Wet"	"N.D."	Control	"Wet"	"N.D."
0-10 cm	4.3(1.5)	10.0(4.4)	6.0(6.0)	5.3(1.5)	1.0(1.0)	5.3(2.9)
10-30 cm*	2.7(1.1)	3.5(0.5)	3.9(2.3)	0.9(0.8)	1.2(0.3)	0.7(0.8)

* to correct counts to compensate for the doubled volume of soil in the 10-30 cm samples the totals were divided by two

Discussion

A complete discussion will be appended to this report following the winter, 1978 meeting of HIPLEX ecology researchers. That discussion will allow integration of this material with the plant biomass, soil moisture, and precipitation data critical to assessing the effects of added water. Those data and interpretation are not yet available to me. Also,the results of 1977 spider, total arthropod carnivore, and arthropod sap-feeding analyses will be available.

Despite the relative taxonomic dissimilarity (Fig. 2) in the grasshopper communities of the grama grass and wheatgrass intensive sites important ecological features are similar. Those include the large number of nymphs in the early season, gradual replacement of early season dominant species by species more adapted to the mid-summer, and the abrupt decline in numbers and biomass after mid-summer. Criddle (1933) and Lea (1958), among others, have noted the close correlation of semiarid land grasshoppers and soil moisture.

Declines in soil moisture have been linked to increases in average grasshopper wing length (allowing a possible increase in migration distance), increased nymph and adult mortality, shift in species composition, and decreased egg production by adult females. Whether or not any correlation exists between the 1977 soil moisture and grasshopper data is not yet known. It is likely that if such a correlation can be found and the ecological relationship is real the grasshoppers alive at the time of soil drought are affected directly by changes in plant condition and indirectly by soil moisture. Development of grasshopper eggs is related to soil moisture through the effects of fungal pathogens and soil temperature. The capacitance meter in use in HIPLEX research may be adequately sensitive to changes in plant physiological status to measure seasonal changes.

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